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भारतीय मानक
Indian Standard

IS 875 (Part 3) : 2015

भवनों और संरचनाओं के लिए डिजाइन लोड (भूकंप की अन्य) — रीति संहिता

भाग 3 हवा भार

(तीसरा पुनरीक्षण)

Design Loads (Other than Earthquake) for Buildings and Structures — Code of Practice

Part 3 Wind Loads

(Third Revision)

ICS 91.100.10

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FOREWORD

This Indian Standard (Part 3) (Third Revision) was adopted by the Bureau of Indian Standards after the draft finalized by the Structural Safety Sectional Committee had been approved by the Civil Engineering Division Council.

A building has to perform many functions satisfactorily. Amongst these functions are the utility of the building for the intended use and occupancy, structural safety, fire safety and compliance with hygienic, sanitation, ventilation and daylight standards. The design of the building is dependent upon the minimum requirements prescribed for each one of the above functions. The minimum requirements pertaining to the structural safety of buildings are being covered in loading codes by way of laying down minimum design loads, which have to be assumed for dead loads, imposed loads, wind loads and other external loads, the structure would be required to bear. Strict conformity to loading standards, it is hoped, will not only ensures the structural safety of the buildings and structures which are being designed and constructed in the country and thereby reduce loss of life and property caused by unsafe structures, but also eliminates the wastage caused by assuming unnecessarily heavy loadings without proper assessment.

This standard was first published in 1957 for the guidance of civil engineers, designers and architects associated with the planning and design of buildings. It included the provisions for the basic design loads (dead loads, live loads, wind loads and seismic loads) to be assumed in the design of the buildings. In its first revision in 1964, the wind pressure provisions were modified on the basis of studies of wind phenomenon and its effect on structures, undertaken by the special Committee in consultation with the Indian Meteorological Department. In addition to this, new clauses on wind loads for butterfly type structures were included; wind pressure coefficients for sheeted roofs, both covered and sloping were modified; seismic load provisions were deleted (separate code having been prepared) and metric system of weights and measurements was adopted.

With the increased adoption of this standard, a number of comments were received on provision of live loads adopted for different occupancies. Subsequently the Committee recommended the formulation of this standard in the following five parts, during the second revision of IS 875 in 1987:

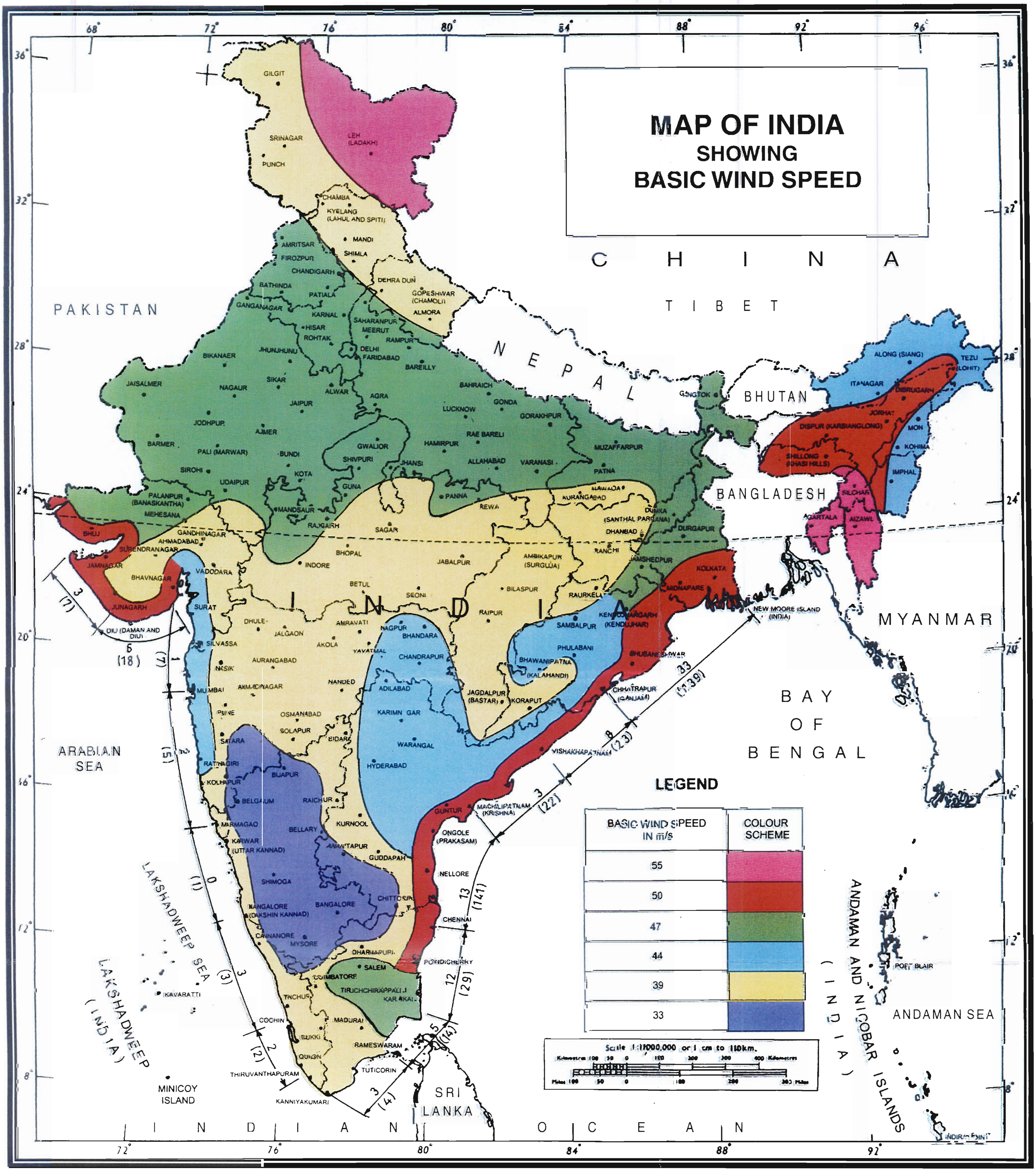
- Part 1 Dead loads
- Part 2 Imposed loads
- Part 3 Wind loads
- Part 4 Snow loads
- Part 5 Special loads and load combinations

This standard (Part 3) deals with wind loads to be considered when designing buildings, structures and components thereof.

In this current revision, the Committee recommends the following modifications/inclusions by taking into account the recent improvements that have been made in the wind engineering descriptive, through R & D efforts nationally and internationally:

a) Aerodynamic roughness heights for individual terrain categories have been explicitly included, and are used to derive turbulence intensity and mean hourly wind speed profiles.
b) The previous classification of structures into B and C classes has been deleted and accordingly the modification factor, k_2 is renamed as terrain roughness and height factor.
c) The values of k_2 factor corresponding to previous class A type structure only, are retained in this standard.
d) An additional modification factor, termed as importance factor has been included for cyclonic regions.
e) Simple empirical expressions have been suggested for height variations of hourly mean wind speed and also turbulence intensity in different terrains.

(*Continued on third cover*)



Based upon Survey of India Outline Map printed in 1993.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.
The boundary of Meghalaya shown on this map is as interpreted from the North-Eastern Areas (Reorganisation) Act, 1971, but has yet to be verified.
Responsibility for correctness of internal details shown on the map rests with the publisher.
The state boundaries between Uttaranchal & Uttar Pradesh, Bihar & Jharkhand and Chhatisgarh & Madhya Pradesh have not been verified by Governments concerned.

FIG. 1 BASIC WIND SPEED IN m/s (BASED ON 50-YEARS RETURN PERIOD)

height of any object surrounding the structure is less than 1.5m. The equivalent aerodynamic roughness height, ($z_{0,1}$) for this terrain is 0.002 m. Typically this category represents open sea-costs and flat plains without trees.

b) *Category2*- Open terrain with well scattered obstructions having heights generally between 1.5 m and 10 m. The equivalent aerodynamic roughness height, ($z_{0,2}$) for this terrain is 0.02 m.

Indian Standard

DESIGN LOADS (OTHER THAN EARTHQUAKE) FOR BUILDINGS AND STRUCTURES — CODE OF PRACTICE

PART 3 WIND LOADS

(Third Revision)

1 SCOPE

1.1 This standard (Part 3) specifies wind forces and their effects (static and dynamic) that should be taken into account when designing buildings, structures and components thereof.

1.2 Wind speeds vary randomly both in time and space and hence assessment of wind loads and response predictions are very important in the design of several buildings and structures. A large majority of structures met with in practice do not however, suffer wind induced oscillations and generally do not require to be examined for the dynamic effects of wind. For such normal, short and heavy structures, estimation of loads using static wind analysis has proved to be satisfactory. The details of this method involving important wind characteristics such as the basic wind speeds, terrain categories, modification factors, wind pressure and force coefficients, etc, are given in **6** and **7**.

1.3 Nevertheless, there are various types of structures or their components such as some tall buildings, chimneys, latticed towers, cooling towers, transmission towers, guyed masts, communication towers, long span bridges, partially or completely solid faced antenna dish, etc, which require investigation of wind induced oscillations. The influence of dynamic velocity fluctuations on the along wind loads (drag loads) for these structures shall be determined using Gust Factor Method, included in **10**. A method for calculation of across wind response of tall buildings and towers is included in **10.3**.

1.4 This standard also applies to buildings or other structures during erection/construction and the same shall be considered carefully during various stages of erection/construction. In locations where the strongest winds and icing may occur simultaneously, loads on structural members, cables and ropes shall be calculated by assuming an ice covering based on climatic and local experience.

1.5 In the design of special structures, such as chimneys, overhead transmission line towers, etc, specific requirements as specified in the respective Codes shall be adopted in conjunction with the provisions of this Code as far as they are applicable. Some of the Indian Standards available for the design of special structures are:

IS No.	*Title*
4998 : 2015	Criteria for design of reinforced concrete chimneys : Part 1 Assessment of loads (*third revision*) (*under print*)
6533	Code of practice for design and construction of steel chimneys
(Part 1) : 1989	Mechanical aspects
(Part 2) : 1989	Structural aspects
5613 (Part 2/ Sec 1) :1985	Code of practice for design, installation and maintenance of overhead power lines : Part 2 Lines above 11 kV, and up to and including 220 kV, Section 1 Design
802 (Part 1/ Sec 1) : 201*	Code of practice for use of structural steel in overhead transmission line towers: Part 1 Materials, Loads and permissible stresses, Section 1 Materials and Loads (*fourth revision*) (*under print*)
11504 : 1985	Criteria for structural design of reinforced concrete natural draught cooling towers
14732 : 2000	Guidelines for the evaluation of the response of occupants of fixed structures, especially buildings and off-shore structures, to low-frequency horizontal motion (0.063 to 1 Hz)

NOTES

1 This standard does not apply to buildings or structures with unconventional shapes, unusual locations, and abnormal environmental conditions that have not been covered in this Code. Special investigations are necessary in such cases to establish wind loads and their effects. Wind tunnel studies may also be required in such situations.

2 In the case of tall structures with unsymmetrical geometry, the designs may have to be checked for torsional effects due to wind pressure.

2 REFERENCES

The following standard contains provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated.

IS No.	*Title*
15498 : 2004	Guidelines for improving the cyclonic resistance of low rise houses and other buildings/structures

3 NOTATIONS

3.1 The following notations shall be followed unless otherwise specified in relevant clauses. Notations have been defined in the text at their first appearance. A few of the notations have more than one definition, having been used for denoting different variables:

A = surface area of a structure or part of a structure;

A_e = effective frontal area;

A_z = the effective frontal area of the building at height z;

b = breadth of a structure or structural member normal to the wind stream in the horizontal plane;

B_s = background factor;

C_d = drag coefficient;

$C_{fd'}$ = force coefficient;

C_{fn} = normal force coefficient;

C_{ft} = transverse force coefficient;

C_f' = frictional drag coefficient;

C_p = pressure coefficient;

C_{pe} = external pressure coefficient;

C_{pi} = internal pressure coefficient;

C_{fs} = cross-wind force spectrum coefficient;

$C_{f,z}$ = drag force coefficient of the building corresponding to the area A_z;

C = coefficient, which depends on θ_s, used in the evaluation of k_3 factor;

d = depth of a structure or structural member parallel to wind stream in the horizontal plane;

d_w = wake width;

D = diameter of cylinder or sphere;

E = wind energy factor;

F_z = along wind load on the building/structure at any height z;

F = force normal to the surface;

f_a = first mode natural frequency of the building/structure in along wind direction in Hz;

f_c = first mode natural frequency of the building/structure in across wind direction in Hz;

f_s = vortex shedding frequency;

F_n = normal force;

F_t = transverse force;

F' = frictional force;

G = gust factor;

g_R = peak factor for resonant response;

g_v = peak factor for upwind velocity fluctuations;

h = height of structure above mean ground level;

h_x = height of development of a velocity profile at a distance x down wind from a change in terrain category;

H_s = height factor for resonant response;

H = height above mean ground level on the topography feature;

I = turbulence intensity;

$I_{h,i}$ = turbulence intensity at height h in terrain category i;

$I_{z,i}$ = turbulence intensity at height z in terrain category i;

IF = interference factor;

k = mode shape power exponent;

k_1, k_2, k_3, k_4 = wind speed modification factors;

$\bar{k}_{2,i}$ = hourly mean wind speed factor;

K = force coefficient multiplication factor for individual members of finite length;

K_a = area averaging factor;

K_c = combination factor;

K_d = wind directionality factor;

l = length of the member or larger horizontal dimension of a building;

L = actual length of upwind slope;

L_e = effective length of upwind slope;

L_h = integral turbulence length scale at the height h;

m_0 = average mass per unit height of the structure;

M_a = design peak along wind base bending moment;

M_c = design peak across wind base bending moment;

N = effective reduced frequency;

p_d = design wind pressure;

p_z = design wind pressure at height z;

$\overline{p}_d$ = design hourly mean wind pressure corresponding to $\overline{V}_{z,d}$;

p_e = external pressure;

p_i = internal pressure;

r = roughness factor which is twice the longitudinal turbulence intensity at height h;

R_e = Reynolds number;

s = level on a building/structure for the evaluation of along wind load effects;

s_0 = factor, which depends on H and X, used for the evaluation of k_3 factor;

S_t = strouhal number;

S = size reduction factor;

V_b = regional basic wind speed;

V_z = design wind speed at height z;

$\overline{V}_d$ = design hourly mean wind speed;

$\overline{V}_{d,z}$ = design hourly mean wind speed at height z;

$\overline{V}_{z,H}$ = hourly mean wind speed at height z;

w = lesser horizontal dimension of a building, or a structural member;

w' = bay width in multi-bay building;

$\hat{\ddot{x}}$ = peak acceleration at the top of the building/structure in along wind direction, in m/s^2;

x = distance down wind from a change in terrain category;

X = distance from the summit or crest of topography feature relative to the effective length, L_e;

$\hat{\ddot{y}}$ = peak acceleration at the top of the building/structure in across wind direction;

z = a height or distance above the ground;

$z_{0,i}$ = aerodynamic roughness height for i^{th} terrain;

Z = effective height of the topography feature;

α = inclination of the roof to the horizontal;

β = damping coefficient of the building/structure;

η = shielding factor;

ϕ = factor to account for the second order turbulence intensity;

Φ = solidity ratio;

Φ_e = effective solidity ratio;

ε = average height of the surface roughness;

θ_s = upwind slope of the topography feature in the wind direction; and

θ = wind angle from a given axis.

4 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

4.1 Angle of Attack — An angle between the direction of wind and a reference axis of the structure.

4.2 Breadth — It means horizontal dimension of the building measured normal to the direction of wind.

NOTE — Breadth and depth are dimensions measured in relation to the direction of wind, whereas length and width are dimensions related to the plan.

4.3 Depth — It means the horizontal dimension of the building measured in the direction of the wind.

4.4 Developed Height — It is the height of upward penetration of the velocity profile in a new terrain. At large fetch lengths, such penetration reaches the gradient height, above which the wind speed may be taken to be constant. At lesser fetch lengths, a velocity profile of a smaller height but similar to that of the fully developed profile of that terrain category has to be taken, with the additional provision that the velocity at the top of this shorter profile equal to that of the un-penetrated earlier velocity profile at that height.

4.5 Effective Frontal Area — The projected area of the structure normal to the direction of wind.

4.6 Element of Surface Area — The area of surface over which the pressure coefficient is taken to be constant.

4.7 Force Coefficient — A non-dimensional coefficient such that the total wind force on a body is the product of the force coefficient, the dynamic pressure of the incident design wind speed and the reference area over which the force is required.

NOTE — When the force is in the direction of the incident wind, the non-dimensional coefficient will be called as 'drag coefficient'. When the force is perpendicular to the direction of incident wind, the non-dimensional coefficient will be called as 'lift coefficient'.

4.8 Ground Roughness — The nature of the earth's surface as influenced by small scale obstructions such as trees and buildings (as distinct from topography) is called ground roughness.

4.9 Gust — A positive or negative departure of wind speed from its mean value, lasting for not more than, say, 2 min over a specified interval of time.

4.10 Peak Gust — A peak gust or peak gust speed is the wind speed associated with the maximum amplitude.

4.11 Fetch Length — It is the distance measured along the wind from a boundary at which a change in the type of terrain occurs. When the changes in terrain types are encountered (such as, the boundary of a town

or city, forest, etc), the wind profile changes in character but such changes are gradual and start at ground level, spreading or penetrating upwards with increasing fetch length.

4.12 Gradient Height — It is the height above the mean ground level at which the gradient wind blows as a result of balance among pressure gradient force, coriolis force and centrifugal force. For the purpose of this Code, the gradient height is taken as the height above the mean ground level, above which the variation of wind speed with height need not be considered.

4.13 High Rise Building (Tall Building) — A building with a height more than or equal to 50 m or having a height to smaller dimension more than 6.

4.14 Low Rise Building — A building having its height less than 20 m.

4.15 Mean Ground Level — The mean ground level is the average horizontal plane of the area enclosed by the boundaries of the structure.

4.16 Pressure Coefficient — It is the ratio of the difference between the pressure acting at a point on the surface and the static pressure of the incident wind to the design wind pressure, where the static and design wind pressures are determined at the height of the point considered after taking into account the geographical location, terrain conditions and shielding effect. The pressure coefficient is also equal to $[1-(V_p/V_z)^2]$, where V_p is the actual wind speed at any point on the structure at a height corresponding to that of V_z.

NOTE — Positive sign of the pressure coefficient indicates pressure acting towards the surface and negative sign indicates pressure acting away from the surface.

4.17 Return Period — It is the number of years, reciprocal of which gives the probability of extreme wind exceeding a given wind speed in anyone year.

4.18 Shielding Effect — Shielding effect or shielding refers to the condition where wind has to pass along some structure(s) or structural element(s) located on the upstream wind side, before meeting the structure or structural element under consideration. A factor called 'shielding factor' is used to account for such effects in estimating the force on the shielded structures.

4.19 Suction — It means pressure less than the atmospheric (static) pressure and is taken to act away from the surface.

4.20 Solidity Ratio — It is equal to the effective area (projected area of all the individual elements) of a frame normal to the wind direction divided by the area enclosed by the boundary of the frame normal to the wind direction.

NOTE — Solidity ratio is to be calculated for individual frames.

4.21 Terrain Category — It means the characteristics of the surface irregularities of an area which arise from natural or constructed features. The categories are numbered in increasing order of roughness.

4.22 Topography — The nature of the earth's surface as influenced by the hill and valley configurations.

4.23 Velocity Profile — The variation of the horizontal component of the atmospheric wind speed at different heights above the mean ground level is termed as velocity profile.

5 GENERAL

5.1 Wind is air in motion relative to the surface of the earth. The primary cause of wind is traced to earth's rotation and differences in terrestrial radiation. The radiation effects are primarily responsible for convection either upwards or downwards. The wind generally blows horizontal to the ground at high wind speeds. Since vertical components of atmospheric motion are relatively small, the term 'wind' denotes almost exclusively the horizontal wind; vertical winds are always identified as such. The wind speeds are assessed with the aid of anemometers or anemographs which are installed at meteorological observatories at heights generally varying from 10 to 30 m above ground.

5.2 Very strong winds (more than 80 kmph) are generally associated with cyclonic storms, thunderstorms, dust storms or vigorous monsoons. A feature of the cyclonic storms over the Indian area is that they rapidly weaken after crossing the coasts and move as depressions/lows inland. The influence of a severe storm after striking the coast does not; in general exceed about 60 km, though sometimes, it may extend even up to 120 km. Very short duration hurricanes of very high wind speeds called Kal Baisaki or Norwesters occur fairly frequently during summer months over North East India.

5.3 The wind speeds recorded at any locality are extremely variable and in addition to steady wind at any time, there are effects of gusts which may last for a few seconds. These gusts cause increase in air pressure but their effect on stability of the building may not be so important; often, gusts affect only part of the building and the increased local pressures may be more than balanced by a momentary reduction in the pressure elsewhere. Because of the inertia of the building, short period gusts may not cause any appreciable increase in stress in main components of the building although the walls, roof sheeting and individual cladding units (glass panels) and their supporting members such as purlins, sheeting rails and glazing bars may be more seriously affected. Gusts can also be extremely important for design of structures with high slenderness

ratios.

5.4 The liability of a building to high wind pressures depends not only upon the geographical location and proximity of other obstructions to air flow but also upon the characteristics of the structure itself.

5.5 The effect of wind on the structure as a whole is determined by the combined action of external and internal pressures acting upon it. In all cases, the calculated wind loads act normal to the surface to which they apply.

5.6 The stability calculations as a whole shall be done considering the combined effect, as well as separate effects of imposed loads and wind loads on vertical surfaces, roofs and other part of the building above general roof level.

5.7 Buildings shall also be designed with due attention to the effects of wind on the comfort of people inside and outside the buildings.

6 WIND SPEED

6.1 Nature of Wind in Atmosphere

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to maximum at a height called the gradient height. There is usually a slight change in direction (Ekman effect) but this is ignored in this standard. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. The average value depends on the average time employed in analyzing the meteorological data and this averaging time varies from few seconds to several minutes. The magnitude of fluctuating component of the wind speed which is called gust, depends on the averaging time. In general, smaller the averaging interval, more is the magnitude of the gust speed.

6.2 BASIC WIND SPEED

Figure 1 gives basic wind speed map of India, as applicable to 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 s and corresponds to mean heights above ground level in an open terrain (Category 2). Basic wind speeds presented in Fig. 1 have been worked out for a 50 year return period. Basic wind speed for some important cities/towns is also given in Annex A.

6.3 Design Wind Speed (V_z)

The basic wind speed (V_b) for any site shall be obtained from Fig. 1 and shall be modified to include the following effects to get design wind speed, V_z at any height z, for the chosen structure:

a) Risk level,
b) Terrain roughness and height of structure,
c) Local topography, and
d) Importance factor for the cyclonic region.

It can be mathematically expressed as follows:

$$V_z = V_b\, k_1\, k_2\, k_3\, k_4$$

where

V_z = design wind speed at height z, in m/s;

k_1 = probability factor (risk coefficient) (*see* **6.3.1**);

k_2 = terrain roughness and height factor (*see* **6.3.2**);

k_3 = topography factor (*see* **6.3.3**); and

k_4 = importance factor for the cyclonic region (*see* **6.3.4**).

NOTE — Wind speed may be taken as constant up to a height of 10 m. However, pressures for buildings less than 10 m high may be reduced by 20 percent for evaluating stability and design of the framing.

6.3.1 *Risk Coefficient (k_1 Factor)* — Figure 1 gives basic wind speeds for terrain Category 2 as applicable at 10 m above ground level based on 50 years mean return period. The suggested life period to be assumed in design and the corresponding k_1 factors for different class of structures for the purpose of design are given in Table 1. In the design of buildings and structures, a regional basic wind speed having a mean return period of 50 years shall be used except as specified in the note of Table 1.

6.3.2 *Terrain, Height Factor (k_2 Factor)*

6.3.2.1 *Terrain*

Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. Wherever sufficient meteorological information is available about the nature of wind direction, the orientation of any building or structure may be suitably planned.

Terrain in which a specific structure stands shall be assessed as being one of the following terrain categories:

a) *Category 1* — Exposed open terrain with few or no obstructions and in which the average

This is the criterion for measurement of regional basic wind speeds and represents airfields, open park lands and undeveloped sparsely built-up outskirts of towns and suburbs. Open land adjacent to sea coast may also be classified as Category 2 due to roughness of large sea waves at high winds.

c) *Category 3* — Terrain with numerous closely spaced obstructions having the size of buildings/structures up to 10 m in height with or without a few isolated tall structures. The equivalent aerodynamic roughness height, ($z_{0,3}$) for this terrain is 0.2 m.

This category represents well wooded areas, and shrubs, towns and industrial areas full or partially developed.

It is likely that the, next higher category than this will not exist in most design situations

Table 1 Risk Coefficients for Different Classes of Structures in Different Wind Speed Zones
(*Clause* 6.3.1)

Sl No.	Class of Structure	Mean Probable Design Life of Structure in Years	k_1 Factor for Basic Wind Speed m/s					
			33	39	44	47	50	55
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	All general buildings and structures	50	1.0	1.0	1.0	1.0	1.0	1.0
ii)	Temporary sheds, structures such as those used during construction operations (for example, formwork and false work), structures during construction stages and boundary walls	5	0.82	0.76	0.73	0.71	0.70	0.67
iii)	Buildings and structures presenting a low degree of hazard to life and property in the event of failure, such as isolated towers in wooded areas, farm buildings other than residential buildings	25	0.94	0.92	0.91	0.90	0.90	0.89
iv)	Important buildings and structures such as hospitals communication buildings/towers, power plant structures	100	1.05	1.06	1.07	1.07	1.08	1.08

NOTE — The factor k_1 is based on statistical concepts which take into account the degree of reliability required and period of time in years during which these will be exposed to wind, that is, life of the structure. Whatever wind speed is adopted for design purposes, there is always a probability (however small) that it may exceed in a storm of exceptional violence; more the period of years over which there is exposure to the wind, more is the probability. Larger return periods ranging from 100 to 1 000 years (implying lower risk level) in association with larger periods of exposure may have to be selected for exceptionally important structures, such as, nuclear power reactors and satellite communication towers. Equation given below may be used in such cases to estimate k_1 factors for different periods of exposure and chosen probability of exceedance (risk level). The probability level of 0.63 is normally considered sufficient for design of buildings and structures against wind effects and the values of k_1 corresponding to this risk level are given above.

$$k_1 = \frac{X_{N,P}}{X_{50,0.63}} = \frac{A - B\left[\ln\left\{-\frac{1}{N}\ln(1-P_N)\right\}\right]}{A+4B}$$

where

N = mean probable design life of structure in years;

P_N = risk level in N consecutive years (probability that the design wind speed is exceeded at least once in N successive years), nominal value = 0.63;

$X_{N,P}$ = extreme wind speed for given values of N and P_N; and

$X_{50,0.63}$ = extreme wind speed for N = 50 years and P_N = 0.63

A and B have the following values for different basic wind speed zones:

Zone m/s	A* m/s	B* m/s
33	23.1 (83.2)	2.6 (9.2)
39	23.3 (84.0)	3.9 (14.0)
44	24.4 (88.0)	5.0 (18.0)
47	24.4 (88.0)	5.7 (20.5)
50	24.7 (88.8)	6.3 (22.8)
55	25.2 (90.8)	7.6 (27.3)

* Values of A and B, in kmph, are given in bracket.

and that selection of a more severe category will be deliberate.

d) *Category 4* — Terrain with numerous large high closely spaced obstructions. The equivalent aerodynamic roughness height, ($z_{0,4}$) for this terrain is 2.0 m.

This category represents large city centers, generally with obstructions above 25 m and well developed industrial complexes.

6.3.2.2 *Variation of wind speed with height in different terrains (k_2 factor)*

Table 2 gives multiplying factors (k_2) by which the basic wind speed given in Fig. 1 shall be multiplied to obtain the wind speed at different heights, in each terrain category.

Table 2 Factors to Obtain Design Wind Speed Variation with Height in Different Terrains

(*Clause* 6.3.2.2)

Sl No.	Height z m	Terrain and Height Multiplier (k_2)			
		Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	1.05	1.00	0.91	0.80
ii)	15	1.09	1.05	0.97	0.80
iii)	20	1.12	1.07	1.01	0.80
iv)	30	1.15	1.12	1.06	0.97
v)	50	1.20	1.17	1.12	1.10
vi)	100	1.26	1.24	1.20	1.20
vii)	150	1.30	1.28	1.24	1.24
viii)	200	1.32	1.30	1.27	1.27
ix)	250	1.34	1.32	1.29	1.28
x)	300	1.35	1.34	1.31	1.30
xi)	350	1.35	1.35	1.32	1.31
xii)	400	1.35	1.35	1.34	1.32
xiii)	450	1.35	1.35	1.35	1.33
xiv)	500	1.35	1.35	1.35	1.34

NOTE — For intermediate values of height z in a given terrain category, use linear interpolation.

6.3.2.3 *Terrain categories in relation to the direction of wind*

The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. Where sufficient meteorological information is available, the basic wind speed may be varied for specific wind direction.

6.3.2.4 *Changes in terrain categories*

The velocity profile for a given terrain category does not develop to full height immediately with the commencement of that terrain category but develop gradually to height (h_x) which increases with the fetch or upwind distance (x).

a) Fetch and developed height relationship — The relation between the developed height (h_x) and the fetch (x) for wind-flow over each of the four terrain categories may be taken as given in Table 3.

b) For structures of heights more than the developed height (h_x) in Table 3, the velocity profile may be determined in accordance with the following:

   1) The less or least rough terrain, or

   2) The method described in Annex B.

Table 3 Fetch and Developed Height Relationship

(*Clause* 6.3.2.4)

Sl No.	Fetch (x) km	Developed Height, h_x m			
		Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
(1)	(2)	(3)	(4)	(5)	(6)
i)	0.2	12	20	35	60
ii)	0.5	20	30	35	95
iii)	1	25	45	80	130
iv)	2	35	65	110	190
v)	5	60	100	170	300
vi)	10	80	140	250	450
vii)	20	120	200	350	500
viii)	50	180	300	400	500

6.3.3 *Topography (k_3 Factor)*

The basic wind speed V_b given in Fig. 1 takes into account the general level of site above sea level. This does not allow for local topographic features such as hills, valleys, cliffs, escarpments, or ridges which can significantly affect wind speed in their vicinity. The effect of topography is to accelerate wind near the summits of hills or crests of cliffs, escarpments or ridges and decelerate the wind in valleys or near the foot of cliffs, steep escarpments, or ridges.

6.3.3.1 The effect of topography shall be significant at a site when the upwind slope (θ) is more than about 3°, and below that, the value of k_3 may be taken to be equal to 1.0. The value of k_3 is confined in the range of 1.0 to 1.36 for slopes more than 3°. A method of evaluating the value of k_3 for values more than 1.0 is given in Annex C. It may be noted that the value of k_3 varies with height above ground level, at a maximum near the ground, and reducing to 1.0 at higher levels.

6.3.4 *Importance Factor for Cyclonic Region (k_4)*

The east coast of India is relatively more vulnerable for occurrences of severe cyclones. On the west coast, Gujarat is vulnerable for severe cyclones. Studies of

wind speed and damage to buildings and structures point to the fact that the speeds given in the basic wind speed map are often exceeded during the cyclones. The effect of cyclonic storms is largely felt in a belt of approximately 60 km width at the coast. In order to ensure better safety of structures in this region (60 km wide on the east coast as well as on the Gujarat Coast), the following values of k_4 (as recommended in IS 15498) are stipulated as applicable according to the importance of the structure:

	k_4
Structures of post-cyclone importance for emergency services (such as cyclone shelters, hospitals, schools, communication towers, etc)	1.30
Industrial structures	1.15
All other structures	1.00

6.4 Hourly Mean Wind Speed

The hourly mean wind speed at height z, for different terrains can be obtained as

$$\overline{V}_{z,H} = \overline{k}_{2,i} V_b$$

where

$\overline{k}_{2,i}$ = hourly mean wind speed factor for terrain category 1

$$= 0.1423 \left[\ln\left(\frac{z}{z_{0,i}}\right) \right] (z_{0,i})^{0.0706}$$

The design hourly mean wind speed at height z can be obtained as:

$$\overline{V}_{z,d} = \overline{V}_{z,H} k_1 k_3 k_4$$
$$= \overline{V}_b k_1 \overline{k}_{2,i} k_3 k_4$$

6.5 Turbulence Intensity

The turbulence intensity variations with height for different terrains can be obtained using the relations given below:

a) *Terrain category 1*

$$I_{z,1} = 0.3507 - 0.0535 \log_{10}\left(\frac{z}{z_{0,1}}\right)$$

b) *Terrain category 2*

$$I_{z,2} = I_{z,1} + \frac{1}{7}\left(I_{z,4} - I_{z,1}\right)$$

c) *Terrain category 3*

$$I_{z,3} = I_{z,1} + \frac{3}{7}\left(I_{z,4} - I_{z,1}\right)$$

d) *Terrain category 4*

$$I_{z,4} = 0.466 - 0.135\,8 \log_{10}\left(\frac{z}{z_{0,4}}\right)$$

6.6 Off Shore Wind Velocity

Cyclonic storms form far away from the sea coast and gradually reduce in speed as they approach the sea coast. Cyclonic storms generally extend up to about 60 km inland after striking the coast. Their effect on land is already reflected in basic wind speeds specified in Fig. 1. The influence of wind speed off the coast up to a distance of about 200 km may be taken as 1.15 times the value on the nearest coast in the absence of any definite wind data. The factor 1.15 shall be used in addition to k_4.

7 WIND PRESSURES AND FORCES ON BUILDINGS/STRUCTURES

7.1 General

The wind load on a building shall be calculated for:

a) Building as a whole,
b) Individual structural elements as roofs and walls, and
c) Individual cladding units including glazing and their fixings.

7.2 Design Wind Pressure

The wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind speed:

$$p_z = 0.6\, V_z^2$$

where

p_z = wind pressure at height z, in N/m^2; and

V_z = design wind speed at height z, in m/s.

The design wind pressure p_d can be obtained as,

$$p_d = K_d K_a K_c p_z$$

where

K_d = wind directionality factor,

K_a = area averaging factor, and

K_c = combination factor (*see* **7.3.3.13**).

The value of p_d, however shall not be taken as less than 0.70 p_z.

NOTES

1 The coefficient 0.6 (in SI units) in the above formula depends on a number of factors and mainly on the atmospheric pressure and air temperature. The value chosen corresponds to the average Indian atmospheric conditions.

2 K_d should be taken as 1.0 when considering local pressure coefficients.

7.2.1 *Wind Directionality Factor, K_d*

Considering the randomness in the directionality of wind and recognizing the fact that pressure or force coefficients are determined for specific wind directions, it is specified that for buildings, solid signs, open signs,

lattice frameworks, and trussed towers (triangular, square, rectangular) a factor of 0.90 may be used on the design wind pressure. For circular or near-circular forms this factor may be taken as 1.0.

For the cyclone affected regions also the factor K_d shall be taken as 1.0.

7.2.2 *Area Averaging Factor,* K_a

Pressure coefficients given in **7.3** are a result of averaging the measured pressure values over a given area. As the area becomes larger, the correlation of measured values decrease and *vice-versa*. The decrease in pressures due to larger areas may be taken into account as given in Table 4.

Table 4 Area Averaging Factor (K_a)
(*Clause* 7.2.2)

Sl No. (1)	Tributary Area (A) m^2 (2)	Area Averaging Factor (Ka)* (3)
i)	≤10	1.0
ii)	25	0.9
iii)	≥100	0.8

* Linear interpolation for intermediate values of a is permitted.

7.2.2.1 *Tributary area*

a) *Overall structure* — For evaluating loads on frames the tributary area shall be taken as the centre to centre distances between frames multiplied by the individual panel dimension in the other direction together with overall pressure coefficients.

b) *Individual elements* — For beam type elements, purlins, etc, the tributary area shall be taken as effective span multiplied by spacing. The effective span is the actual span for mid span and cantilever load effects; and half the sum of adjacent spans for support moments and reactions.

For plate type elements, the area of individual plates between supports is taken as the tributary area.

For glass cladding, individual pane area of glass is the tributary area.

7.3 Pressure Coefficients

The pressure coefficients are always given for a particular surface or part of the surface of a building. The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient (C_p) and the design wind pressure at the height of the surface from the ground. The average values of these pressure coefficients for some building shapes are given in **7.3.2** and **7.3.3**.

Average values of pressure coefficients are given for critical wind directions in one or more quadrants. In order to determine the maximum wind load on the building, the total load should be calculated for each of the critical directions shown from all quadrants. Where considerable variation of pressure occurs over a surface, it has been sub-divided and mean pressure coefficients given for each of its several parts.

In addition, areas of high local suction (negative pressure concentration) frequently occurring near the edges of walls and roofs are separately shown. Coefficients for the local effects should only be used for calculation of forces on these local areas affecting roof sheeting, glass panels, and individual cladding units including their fixtures. They should not be used for calculating force on entire structural elements such as roof, walls or structure as a whole.

NOTES

1 The pressure coefficients given in different tables have been obtained mainly from measurements on models in wind tunnels, and the great majority of data available has been obtained in conditions of relatively smooth flow. Where sufficient field data exists as in the case of rectangular buildings, values have been obtained to allow for turbulent flow.

2 In recent years, wall glazing and cladding design has been a source of major concern. Although of less consequence than the collapse of main structures, damage to glass can be hazardous and cause considerable financial losses.

3 For pressure coefficients for structures not covered here, reference may be made to specialist literature on the subject or advice may be sought from specialists in the subject.

7.3.1 *Wind Load on Individual Members*

When calculating the wind load on individual structural elements such as roofs and walls, and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite faces of such elements or units. For clad structures, it is, therefore, necessary to know the internal pressure as well as the external pressure. Then the wind load, F, acting in a direction normal to the individual structural element or cladding unit is:

$$F = (C_{pe} - C_{pi})\, A\, p_d$$

where

C_{pe} = external pressure coefficient,

C_{pi} = internal pressure coefficient,

A = surface area of structural element or cladding unit, and

p_d = design wind pressure.

NOTES

1 If the surface design pressure varies with height, the surface areas of the structural element may be sub-divided so that the specified pressures are taken over appropriate areas.

2 Positive wind load indicates the force acting towards the structural element and negative away from it.

7.3.2 *Internal Pressure Coefficients*

Internal air pressure in a building depends upon the degree of permeability of cladding to the flow of air. The internal air pressure may be positive or negative depending on the direction of flow of air in relation to openings in the buildings.

7.3.2.1 In the case of buildings where the claddings permit the flow of air with openings not more than about 5 percent of the wall area but where there are no large openings, it is necessary to consider the possibility of the internal pressure being positive or negative. Two design conditions shall be examined, one with an internal pressure coefficient of +0.2 and another with an internal pressure coefficient of –0.2.

The internal pressure coefficient is algebraically added to the external pressure coefficient and the analysis which indicates greater distress of the member shall be adopted. In most situations a simple inspection of the sign of external pressure will at once indicate the proper sign of the internal pressure coefficient to be taken for design.

NOTE — The term normal permeability relates to the flow of air commonly afforded by claddings not only through open windows and doors, but also through the slits round the closed windows and doors and through chimneys, ventilators and through the joints between roof coverings, the total open area being less than 5 percent of area of the walls having the openings.

7.3.2.2 *Buildings with medium and large openings*

Buildings with medium and large openings may also exhibit either positive or negative internal pressure depending upon the direction of wind. Buildings with medium openings between about 5 and 20 percent of wall area shall be examined for an internal pressure coefficient of +0.5 and later with an internal pressure coefficient of –0.5, and the analysis which produces greater distress of the member shall be adopted. Buildings with large openings, that is, openings larger than 20 percent of the wall area shall be examined once with an internal pressure coefficient of +0.7 and again with an internal pressure coefficient of –0.7, and the analysis which produces greater distress of the member shall be adopted.

Buildings with one open side or opening exceeding 20 percent of wall area may be assumed to be subjected to internal positive pressure or suction similar to those of buildings with large openings. A few examples of buildings with one side openings are shown in Fig. 2 indicating values of internal pressure coefficients with respect to the direction of wind.

7.3.3 *External Pressure Coefficients*

7.3.3.1 *Walls*

The average external pressure coefficient for the walls of clad buildings of rectangular plan shall be as given in Table 5. In addition, local pressure concentration coefficients are also given.

7.3.3.2 *Pitched, hipped and mono slope roofs of clad buildings*

The average external pressure coefficients and pressure concentration coefficients for pitched roofs of rectangular clad building shall be as given in Table 6. Where no pressure concentration coefficients are given, the average coefficients shall apply. The pressure coefficients on the under-side of any overhanging roof shall be taken in accordance with 7.3.3.5.

For mono slope roofs of rectangular clad buildings, the average pressure coefficient and pressure concentration coefficient for mono slope (lean-to) roofs of rectangular clad buildings shall be as given in Table 7.

NOTES

1 The pressure concentration shall be assumed to act outward (suction pressure) at the ridges, eaves, cornices and 90° corners of roofs.

2 The pressure concentration shall not be included with the net external pressure when computing overall load.

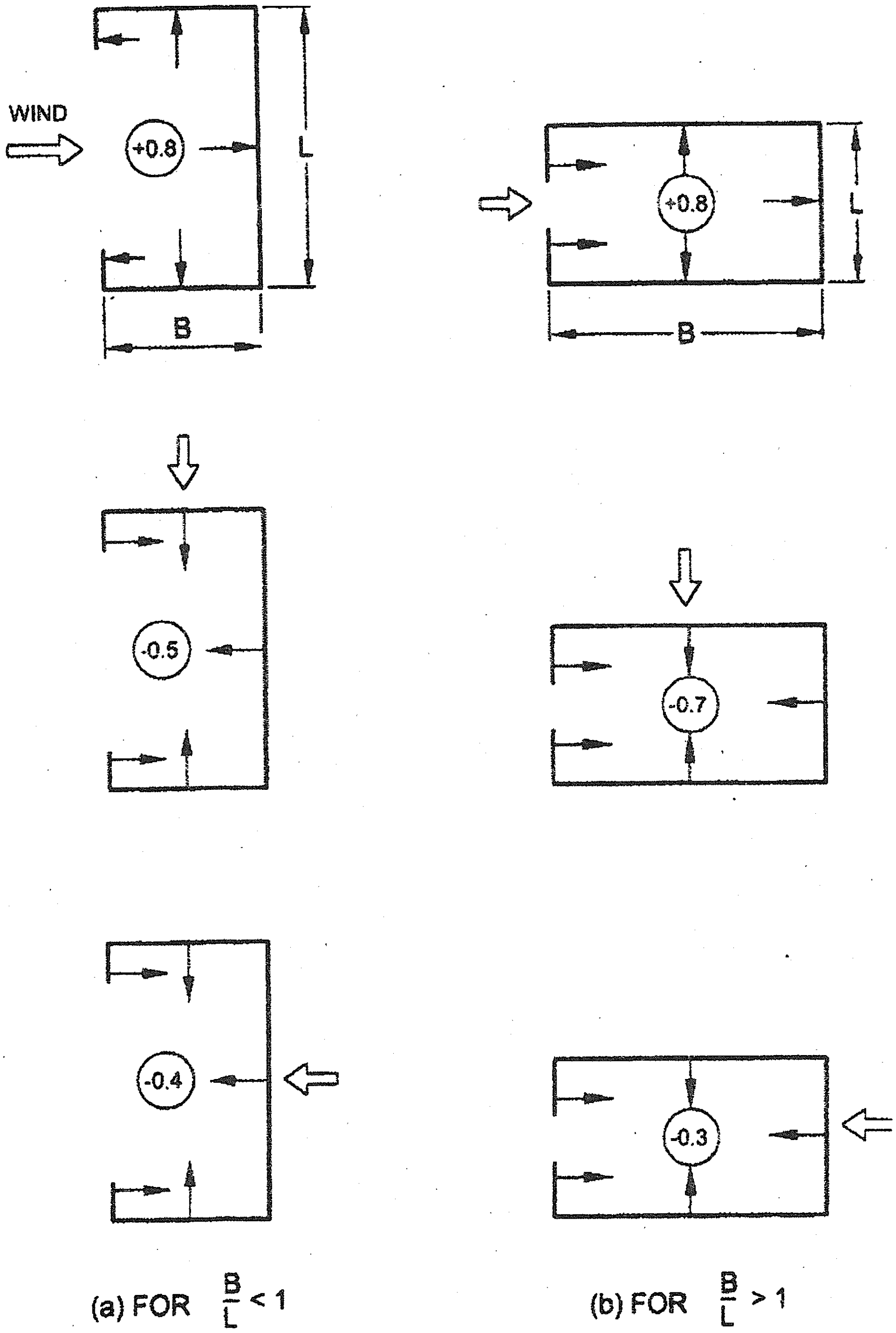
3 For hipped roofs, pressure coefficients (including local values) may be taken on all the four slopes, as appropriate from Table 6, and be reduced by 20 percent for the hip slope.

7.3.3.3 *Canopy roofs with* ($1/4 < h/w < 1$ *and* $1 < L/w < 3$)

The pressure coefficients are given in Tables 8 and 9 separately for mono-pitch and double pitch canopy roofs such as open-air parking garages, shelter areas, outdoor areas, railway platforms, stadia and theatres. The coefficients take into account of the combined effect of the wind exerted on and under the roof for all wind directions; the resultant is to be taken normal to the canopy. Where the local coefficients overlap, the greater of the two given values should be taken. However, the effect of partial closures of one side and or both sides, such as those due to trains, buses and stored materials shall be foreseen and taken into account.

The solidity ratio f is equal to the area of obstructions under the canopy divided by the gross area under the canopy, both areas normal to the wind direction. f = 0 represents a canopy with no obstructions underneath. f = 1 represents the canopy fully blocked with contents to the downwind eaves. Values of C_p for intermediate solidities may be linearly interpolated between these two extremes, and apply upwind of the position of maximum blockage only. For downwind of the position of maximum blockage, the coefficients for f = 0 may be used.

In addition to the forces due to the pressures normal to the canopy, there will be horizontal loads on the canopy



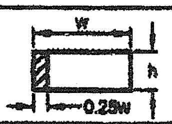
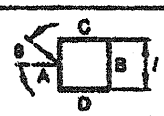
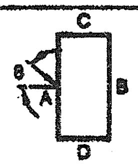
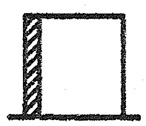
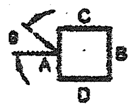
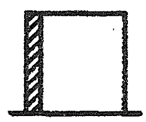
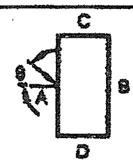
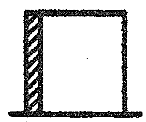
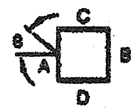
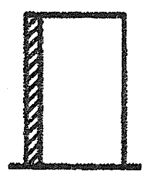
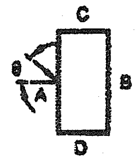
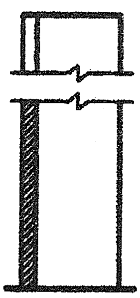
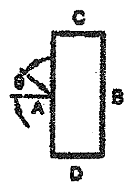
(c) FOR $\frac{B}{L} = 1$, USE AVERAGE VALUES

(ARROWS INDICATE DIRECTION OF WIND FLOW)

FIG. 2 BUILDINGS WITH ONE SIDE OPENINGS

Table 5 External Pressure Coefficients (C_{pe}) for Walls of Rectangular Clad Buildings

(*Clause* 7.3.3.1)

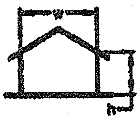
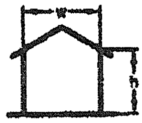
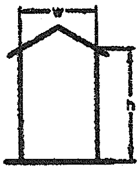
BUILDING HEIGHT RATIO	BUILDING PLAN RATIO	ELEVATION	PLAN	WIND ANGLE θ	C_{pe} FOR SURFACE A	B	C	D	LOCAL C_{pe}
				Degrees					
$\frac{h}{w}\le\frac{1}{2}$	$1<\frac{l}{w}\le\frac{3}{2}$			0	+0.7	-0.2	-0.5	-0.5	-0.8
				90	-0.5	-0.5	+0.7	-0.2	
	$\frac{3}{2}<\frac{l}{w}<4$			0	+0.7	-0.25	-0.6	-0.6	-1.0
				90	-0.5	-0.5	+0.7	-0.1	
$\frac{1}{2}<\frac{h}{w}\le\frac{3}{2}$	$1\le\frac{l}{w}\le\frac{3}{2}$			0	+0.7	-0.25	-0.6	-0.6	-1.1
				90	-0.6	-0.6	+0.7	-0.25	
	$\frac{3}{2}\le\frac{l}{w}<4$			0	+0.7	-0.3	-0.7	-0.7	-1.1
				90	-0.5	-0.5	+0.7	-0.1	
$\frac{3}{2}<\frac{h}{w}<6$	$1<\frac{l}{w}\le\frac{3}{2}$			0	+0.8	-0.25	-0.8	-0.8	-1.2
				90	-0.8	-0.8	+0.8	-0.25	
	$\frac{3}{2}\le\frac{l}{w}<4$			0	+0.7	-0.4	-0.7	-0.7	-1.2
				90	-0.5	-0.5	+0.8	-0.1	
$\frac{h}{w}\ge6$	$\frac{l}{w}=\frac{3}{2}$			0	+0.95	-1.85	-0.9	-0.9	1.25
				90	-0.8	-0.8	+0.9	-0.85	
	$\frac{l}{w}=1.0$			0	+0.95	-1.25	-0.7	-0.7	1.25
				90	-0.7	-0.7	+0.95	-1.25	
	$\frac{l}{w}=2$			0	+0.85	-0.75	-0.75	-0.75	1.25
				90	-0.75	-0.75	+0.85	-0.75	

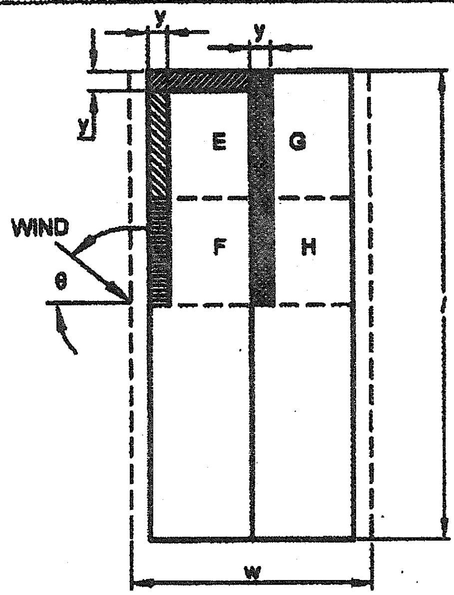
NOTE

h is the height to eaves or parapet, *l* is the greater horizontal dimensions of a building and *w* is the lesser horizontal dimensions of a building.

Table 6 External Pressure Coefficients (Cpe) for Pitched Roofs of Rectangular Clad Buildings

(*Clause* 7.3.3.2)

BUILDING HEIGHT RATIO		ROOF ANGLE α	WIND ANGLE θ 0° EF	WIND ANGLE θ 0° GH	WIND ANGLE θ 90° EG	WIND ANGLE θ 90° FH	LOCAL COEFFICIENTS (1)	LOCAL COEFFICIENTS (2)	LOCAL COEFFICIENTS (3)	LOCAL COEFFICIENTS (4)
		Degrees								
$\frac{h}{w} \leq \frac{1}{2}$		0	-0.8	-0.4	-0.8	-0.4	-2.0	-2.0	-2.0	—
		5	-0.9	-0.4	-0.8	-0.4	-1.4	-1.2	-1.2	-1.0
		10	-1.2	-0.4	-0.8	-0.6	-1.4	-1.4		-1.2
		20	-0.4	-0.4	-0.7	-0.6	-1.0			-1.2
		30	0	-0.4	-0.7	-0.6	-0.8			-1.1
		45	+0.3	-0.6	-0.7	-0.6				-1.1
		60	+0.7	-0.6	-0.7	-0.6				-1.1
$\frac{1}{2} < \frac{h}{w} \leq \frac{3}{2}$		0	-0.8	-0.6	-1.0	-0.6	-2.0	-2.0	-2.0	—
		5	-0.9	-0.6	-0.9	-0.6	-2.0	-2.0	-1.5	-1.0
		10	-1.1	-0.6	-0.8	-0.6	-2.0	-2.0	-1.5	-1.2
		20	-0.7	-0.5	-0.8	-0.6	-1.5	-1.5	-1.5	-1.0
		30	-0.2	-0.5	-0.8	-0.8	-1.0			-1.0
		45	+0.2	-0.5	-0.8	-0.8				
		60	+0.6	-0.5	-0.8	-0.8				
$\frac{3}{2} < \frac{h}{w} < 6$		0	-0.7	-0.6	-0.9	-0.7	-2.0	-2.0	-2.0	—
		5	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.0
		10	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.2
		20	-0.8	-0.6	-0.8	-0.8	-1.5	-1.5	-1.5	-1.2
		30	-1.0	-0.5	-0.8	-0.7	-1.5			
		40	-0.2	-0.5	-0.8	-0.7	-1.0			
		50	+0.2	-0.5	-0.8	-0.7				
		60	+0.5	-0.5	-0.8	-0.7				



KEY PLAN

$y = h$ or $0.15\,w$

Whichever is the lesser.

NOTE

1 h is the height to eaves or parapet and w is the lesser horizontal dimension of a building.

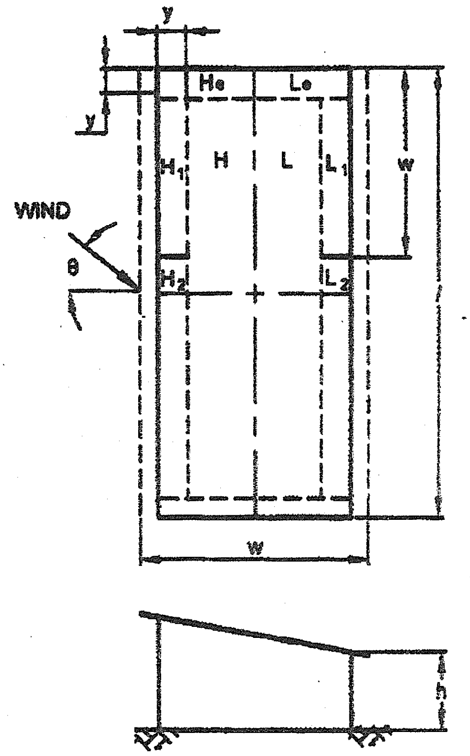
2 Where no local coefficients are given, the overall coefficient apply.

3 For hipped roofs the local coefficient for the hip ridge may be conservatively taken as the the appropriate ridge value.

4 w and l are dimensions between the walls excluding overhangs.

Table 7 External Pressure Coefficients (Cpe) for Monoslope Roofs of Rectangular Clad Buildings $\frac{h}{w} < 2$

(*Clause* 7.3.3.2)



y = *h* or 0.15 *w*

Whichever is the lesser.

NOTE :- Area *H* and area *L* refer to the whole quadrant.

ROOF ANGLE α	WIND ANGLE θ										LOCAL COEFFICIENTS (C_{pe})					
	0°		45°		90°		135°		180°							
	H	*L*	*H*	*L*	*H* & *L* *	*H* & *L* **	*H*	*L*	*H*	*L*	H_1	H_2	L_1	L_2	H_e	L_e
Degrees																
5	-1.0	-0.5	-1.0	-0.9	-1.0	-0.5	-0.9	-1.0	-0.5	-1.0	-2.0	-1.5	-2.0	-1.5	-2.0	-2.0
10	-1.0	-0.5	-1.0	-0.8	-1.0	-0.5	-0.8	-1.0	-0.4	-1.0	-2.0	-1.5	-2.0	-1.5	-2.0	-2.0
15	-0.9	-0.5	-1.0	-0.7	-1.0	-0.5	-0.6	-1.0	-0.3	-1.0	-1.8	-0.9	-1.8	-1.4	-2.0	-2.0
20	-0.8	-0.5	-1.0	-0.6	-0.9	-0.5	-0.5	-1.0	-0.2	-1.0	-1.8	-0.8	-1.8	-1.4	-2.0	-2.0
25	-0.7	-0.5	-1.0	-0.6	-0.8	-0.5	-0.3	-0.9	-0.1	-0.9	-1.8	-0.7	-0.9	-0.9	-2.0	-2.0
30	-0.5	-0.5	-1.0	-0.6	-0.8	-0.5	-0.1	-0.6	0	-0.6	-1.8	-0.5	-0.5	-0.5	-2.0	-2.0

* Applied to length *w/2* from wind-ward end. ** Applies to remainder

NOTE

1 *h* is the height of eaves at lower side, is the greater horizontal dimensions of a building and *w* is the lesser horizontal dimension of a building.

2 *l* and *w* are overall length and width including overhangs.

due to the wind pressure on any fascia and to friction over the surface of the canopy. For any wind direction, only the greater of these two forces need to be taken into account. Fascia loads should be calculated on the area of the surface facing the wind, using a force coefficient of 1.3. Frictional drag should be calculated using the coefficients given in 7.4.1.

NOTE — Tables 10 to 15 may be used to get internal and external pressure coefficients for pitches and troughed free roofs for some specific cases for which aspect ratios and roof slopes have been specified. However, while using Tables 10 to 15 any significant departure from it should be investigated carefully. No increase shall be made for local effects except as indicated.

7.3.3.4 *Pitched and saw-tooth roofs multi-span buildings*

For pitched and saw-tooth roofs of multi-span buildings, the external average pressure coefficients shall be as given in Tables 16 and 17 respectively provided that all the spans shall be equal and the height to the eaves shall not exceed the span.

7.3.3.5 *Pressure coefficients on overhangs from roofs*

The pressure coefficients on the top over-hanging portion of the roofs shall be taken to be the same as that of the nearest top portion of the non-overhanging portion of the roofs. The pressure coefficients for the underside surface of the over-hanging portions shall be taken as follows and shall be taken as positive if the overhanging portion is on the windward side:

a) 1.25, if the overhanging slopes, downwards;
b) 1.00, if the overhanging is horizontal; and
c) 0.75, if the overhanging slopes upwards.

For overhanging portions on sides other than windward side, the average pressure coefficients on adjoining walls may be used.

7.3.3.6 *Curved roofs*

For curved roofs the external pressure coefficients shall be as given in Table 18. Allowance for local effects shall be made in accordance with Table 6. Two values of C_2 have been given for elevated curved roofs. Both the load cases have to be analyzed, and critical load effects are to be considered in design.

7.3.3.7 *Cylindrical structures*

For the purpose of calculating the wind pressure distribution around a cylindrical structure of circular cross-section, the value of external pressure coefficients given in Table 19 may be used, provided that the Reynolds number is more than 10 000. They may be used for wind blowing normal to the axis of cylinders having axis normal to the ground plane (that is, chimneys and silos) and cylinders having their axis parallel to the ground plane (that is, horizontal tanks), provided that the clearance between the tank and the ground is not less than the diameter of the cylinder. h is height of a vertical cylinder or length of a horizontal cylinder. Where there is a free flow of air around both ends, h is to be taken as half the length when calculating h/D ratio.

In the calculation of resultant load on the periphery of the cylinder, the value of C_{pi} shall be taken into account. For open ended cylinders, C_{pi} shall be taken as follows:

a) -0.8, where h/D is more than or equal to 0.3; and
b) -0.5, where h/D is less than 0.3.

7.3.3.8 *Roofs and bottoms of cylindrical elevated structures*

The external pressure coefficients for roofs and bottoms of cylindrical elevated structures shall be as given in Table 20.

Alternately, the pressure distribution given in Fig. 3 can be used together with the force coefficients given in Table 25 for the cylindrical portion.

7.3.3.9 *Combined roofs*

The average external pressure coefficients for combined roofs are shown in Table 21.

7.3.3.10 *Roofs with skylight*

The average external pressure coefficients for roofs with skylight are shown in Table 22.

7.3.3.11 *Grandstands*

The pressure coefficients on the roof (top and bottom) and rear wall of a typical grandstand roof which is open on three sides are given in Table 23. The pressure coefficients are valid for a particular ratio of dimensions as specified in Table 21 but may be used for deviations up to 20 percent. In general, the maximum wind load occurs when the wind is blowing into the open front of the stand, causing positive pressure under the roof and negative pressure on the roof.

7.3.3.12 *Spheres*

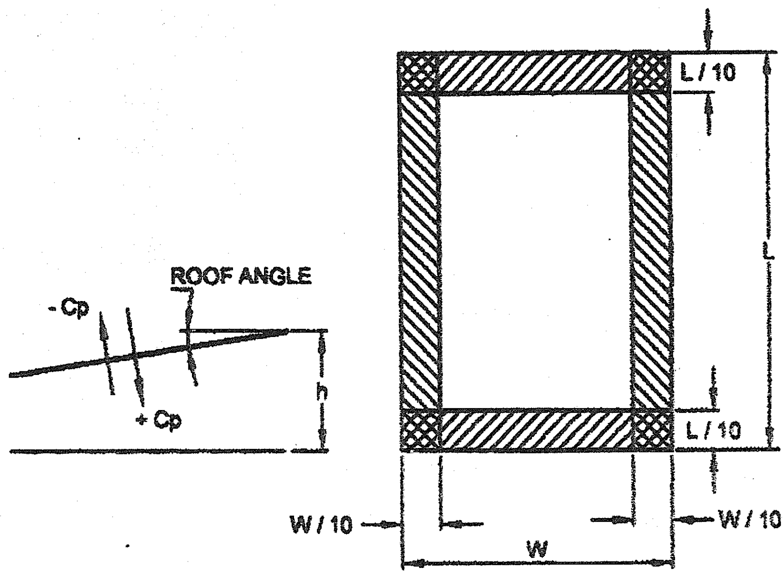
The external pressure coefficients for spheres shall be as given in Table 24.

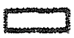
7.3.3.13 *Frames*

When taking wind loads on frames of clad buildings it is reasonable to assume that the pressures or suctions inside and outside the structure shall not be fully correlated. Therefore when taking the combined effect of wind loads on the frame, a reduction factor of $K_c = 0.90$ may be used over the building envelope when roof is subjected to pressure and internal pressure is suction, or *vice-versa*.

Table 8 Pressure Coefficients for Monoslope Free Roofs

(*Clause* 7.3.3.3)



ROOF ANGLE (Degree) α	SOLIDITY RATIO Φ	MAXIMUM (LARGEST + ve) AND MINIMUM (LARGEST - ve) PRESSURE COEFFICIENTS			
		OVERALL COEFFICIENTS	LOCAL COEFFICIENTS		
					
0 5 10 15 20 25 30	All values of Φ	+ 0.2 + 0.4 + 0.5 + 0.7 + 0.8 + 1.0 + 1.2	+ 0.5 + 0.8 + 1.2 + 1.4 + 1.7 + 2.0 + 2.2	+ 1.8 + 2.1 + 2.4 + 2.7 + 2.9 + 3.1 + 3.2	+ 1.1 + 1.3 + 1.6 + 1.8 + 2.1 + 2.3 + 2.4
0	Φ = 0	- 0.5	- 0.6	- 1.3	- 1.4
	Φ = 1	- 1.0	- 1.2	- 1.8	- 1.9
5	Φ = 0	- 0.7	- 1.1	- 1.7	- 1.8
	Φ = 1	- 1.1	- 1.6	- 2.2	- 2.3
10	Φ = 0	- 0.9	- 1.5	- 2.0	- 2.1
	Φ = 1	- 1.3	- 2.1	- 2.6	- 2.7
15	Φ = 0	- 1.1	- 1.8	- 2.4	- 2.5
	Φ = 1	- 1.4	- 2.3	- 2.9	- 3.0
20	Φ = 0	- 1.3	- 2.2	- 2.8	- 2.9
	Φ = 1	- 1.5	- 2.6	- 3.1	- 3.2
25	Φ = 0	- 1.6	- 2.6	- 3.2	- 3.2
	Φ = 1	- 1.7	- 2.8	- 3.5	- 3.5
30	Φ = 0	- 1.8	- 3.0	- 3.8	- 3.6
	Φ = 1	- 1.8	- 3.0	- 3.8	- 3.6

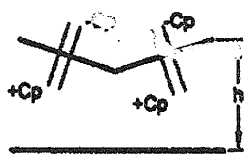
NOTES

1 For monopitch canopies the centre of pressure should be taken to act at 0.3 w from the windward edge.

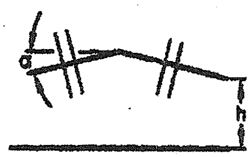
2 W and L are overall width and length including overhangs,

Table 9 Pressure Coefficients for Free Standing Double Sloped Roofs

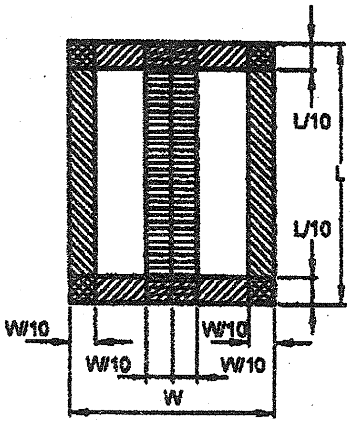
(*Clause* 7.3.3.3)



- ve ROOF ANGLE



+ ve ROOF ANGLE



KEY PLAN

ROOF ANGLE (Degrees) α	SOLIDITY RATIO Φ	MAXIMUM (LARGEST + ve) AND MINIMUM (LARGEST - ve) PRESSURE COEFFICIENTS				
		OVERALL COEFFICIENTS	LOCAL COEFFICIENTS			
- 20	All values of Φ	+ 0.7	+ 0.8	+ 1.6	+ 0.6	+ 1.7
- 15		+ 0.5	+ 0.6	+ 1.5	+ 0.7	+ 1.4
- 10		+ 0.4	+ 0.6	+ 1.4	+ 0.8	+ 1.1
- 5		+ 0.3	+ 0.5	+ 1.5	+ 0.8	+ 0.8
+ 5		+ 0.3	+ 0.6	+ 1.8	+ 1.3	+ 0.4
+ 10		+ 0.4	+ 0.7	+ 1.8	+ 1.4	+ 0.4
+ 15		+ 0.4	+ 0.9	+ 1.9	+ 1.4	+ 0.4
+ 20		+ 0.6	+ 1.1	+ 1.9	+ 1.5	+ 0.4
+ 25		+ 0.7	+ 1.2	+ 1.9	+ 1.6	+ 0.5
+ 30		+ 0.9	+ 1.3	+ 1.9	+ 1.6	+ 0.7
- 20	Φ = 0	- 0.7	- 0.9	- 1.3	- 1.6	- 0.6
	Φ = 1	- 0.9	- 1.2	- 1.7	- 1.9	- 1.2
- 15	Φ = 0	- 0.6	- 0.8	- 1.3	- 1.6	- 0.6
	Φ = 1	- 0.8	- 1.1	- 1.7	- 1.9	- 1.2
- 10	Φ = 0	- 0.6	- 0.8	- 1.3	- 1.5	- 0.6
	Φ = 1	- 0.8	- 1.1	- 1.7	- 1.9	- 1.3
- 5	Φ = 0	- 0.5	- 0.7	- 1.3	- 1.6	- 0.6
	Φ = 1	- 0.8	- 1.5	- 1.7	- 1.9	- 1.4
+ 5	Φ = 0	- 0.6	- 0.6	- 1.4	- 1.4	- 1.1
	Φ = 1	- 0.9	- 1.3	- 1.8	- 1.8	- 2.1
+ 10	Φ = 0	- 0.7	- 0.7	- 1.5	- 1.4	- 1.4
	Φ = 1	- 1.1	- 1.4	- 2.0	- 1.8	- 2.4
+ 15	Φ = 0	- 0.8	- 0.9	- 1.7	- 1.4	- 1.8
	Φ = 1	- 1.2	- 1.5	- 2.2	- 1.9	- 2.8
+ 20	Φ = 0	- 0.9	- 1.2	- 1.8	- 1.4	- 2.0
	Φ = 1	- 1.3	- 1.7	- 2.3	- 1.9	- 3.0
+ 25	Φ = 0	- 1.0	- 1.4	- 1.9	- 1.4	- 2.0
	Φ = 1	- 1.4	- 1.9	- 2.4	- 2.1	- 3.0
+ 30	Φ = 0	- 1.0	- 1.4	- 1.9	- 1.4	- 2.0
	Φ = 1	- 1.4	- 2.1	- 2.6	- 2.2	- 3.0

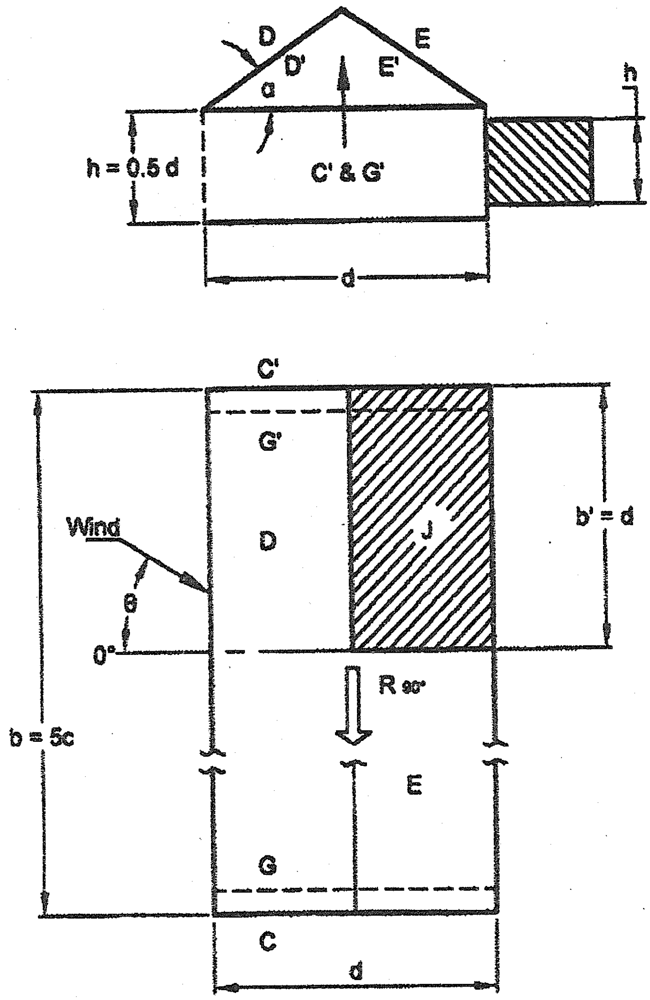
NOTES

1 Each slope of a duopitch canopy should be able to withstand forces using both the maximum and the minimum coefficients, and the whole canopy should be able to support forces using one slope at the maximum coefficient with the other slope at the minimum coefficient. For duoptich canopies the centre of pressure should be taken to act at the centre of each slope.

2 *W* and *L* are overall width and length including overhangs

Table 10 Pressure Coefficients (Top and Bottom) for Pitched Roofs, Roof Slope $\alpha = 30°$

(*Clause* 7.3.3.3)

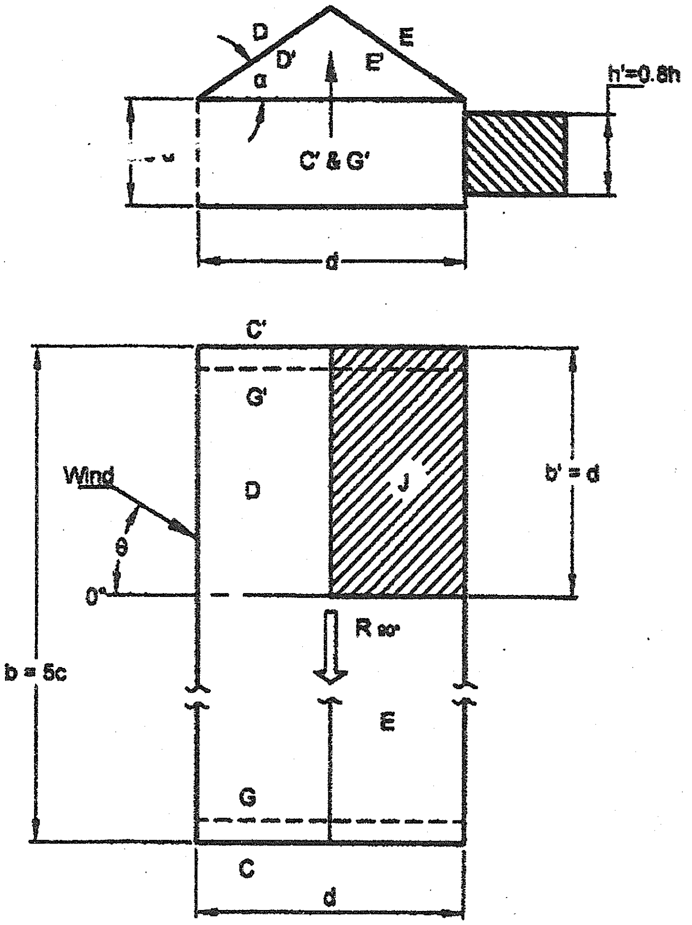


Roof slope $\alpha = 30°$
$\theta = 0° - 45°$, *D, D', E, E'* full length.
$\theta = 90°$, *D, D', E, E'* part length.
b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	+0.8	-1.0	-0.5	-0.9				
45°	+0.1	-0.3	-0.6	-0.3	-0.3	-0.8	-0.3	-0.4
90°	-0.3	-0.4	-0.3	-0.4				
For all value of θ	For J : C_p Top = 1.0, C_p bottom = - 0.2 Tangentially acting friction : $R_{90°} = 0.05\, p_d\, bd$							

Table 11 Pressure Coefficients (Top and Bottom) for Pitched Roofs, Roof α = 30° with effects of Train or Stored Material

(*Clause* 7.3.3.3)

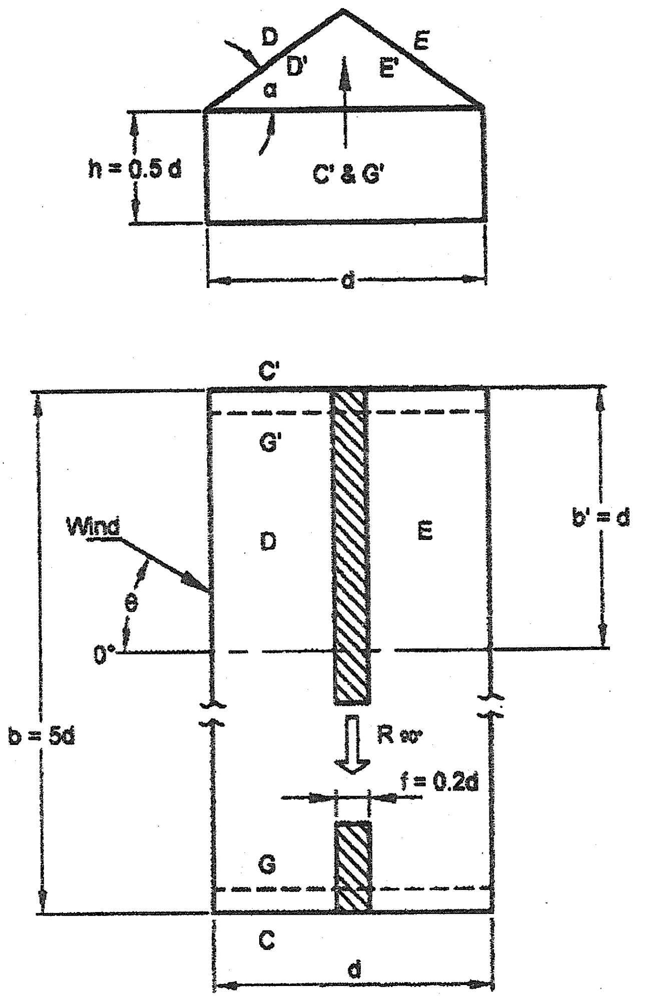


Roof slope $\alpha = 30°$
Effects of trains or stored materials.
$\theta = 0° - 45°$, or $135° - 180°$, *D, D', E, E'* full length.
$\theta = 90°$, *D, D'*, E, E' part length.
b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	+ 0.1	+ 0.8	- 0.7	+ 0.9	- 0.3	+ 0.8	+ 0.3	- 0.4
45°	- 0.1	+ 0.5	- 0.8	+ 0.5				
90°	- 0.4	- 0.5	- 0.4	- 0.5				
180°	- 0.3	- 0.6	+ 0.4	- 0.6				
For all value of θ	For J : C_p Top = -1.5, C_p bottom = 0.5 Tangentially acting friction : $R_{90°} = 0.05\, p_d\, bd$							

Table 12 Pressure Coefficients (Top and Bottom) for Pitched Roofs, $\alpha = 10°$

(*Clause* 7.3.3.3)

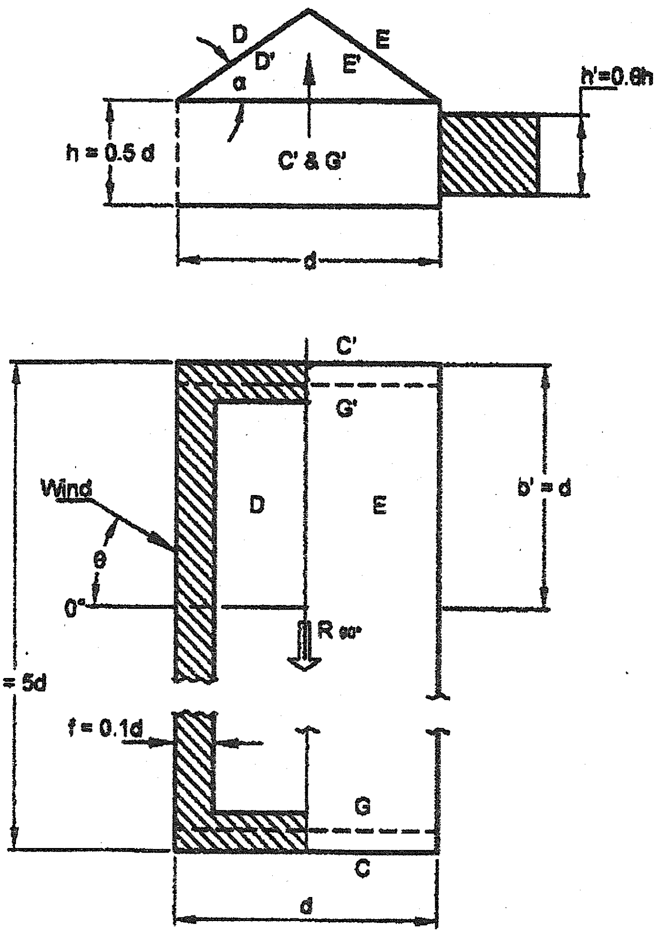


Roof slope $\alpha = 10°$
$\theta = 0° - 45°$, *D, D', E, E'* full length.
$\theta = 60°$, *D, D', E, E'* part length.
b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
					END SURFACES			
	D	*D'*	*E*	*E'*	*C*	*C'*	*G*	*G'*
0° 45° 90°	- 1.0 - 0.3 - 0.3	+ 0.3 + 0.1 0	- 0.5 - 0.3 - 0.3	+ 0.2 + 0.1 0	- 0.4	+ 0.8	+ 0.3	- 0.6
For all value of θ	For *f* : C_p Top = - 1.0, C_p bottom = 0.4 Tangentially acting friction : $R_{90°} = 0.1\, p_d\, bd$							

Table 13 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, $\alpha = 10°$ with effects of Train or Stored Materials

(*Clause* 7.3.3.3)

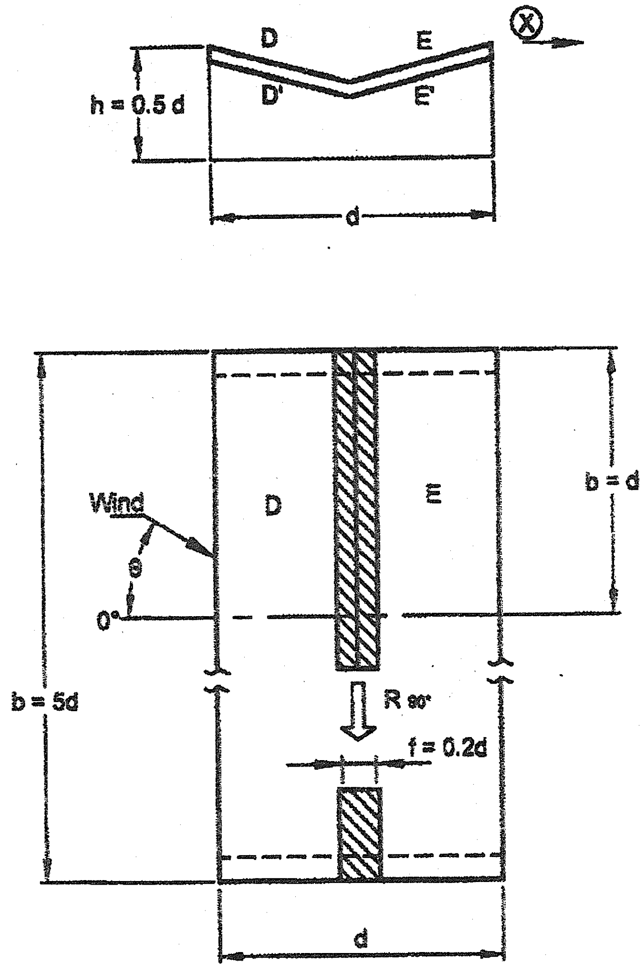


Roof slope $\alpha = 10°$
Effects of trains or stored materials.
$\theta = 0°$- 45°, or 135° - 180°, *D, D', E, E'* full length.
$\theta = 90°$, *D, D', E, E'* part length.
b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0° 45° 90° 180°	- 1.3 - 0.5 - 0.3 - 0.4	+ 0.8 + 0.4 0 - 0.3	- 0.6 - 0.3 - 0.3 - 0.6	0.7 + 0.3 0 - 0.3	- 0.4	+ 0.8	+ 0.3	- 0.6
For all value of θ	For *f* : C_p Top = -1.6, C_p bottom = - 0.9 Tangentially acting friction : $R_{90°} = 0.1 p_d bd$							

Table 14 Pressure Coefficients for Troughed Free Roofs, $\alpha = 10°$

(*Clause* 7.3.3.3)



Roof slope $\alpha = 10°$

$\theta = 0° - 45°$, *D, D', E, E'* full length.

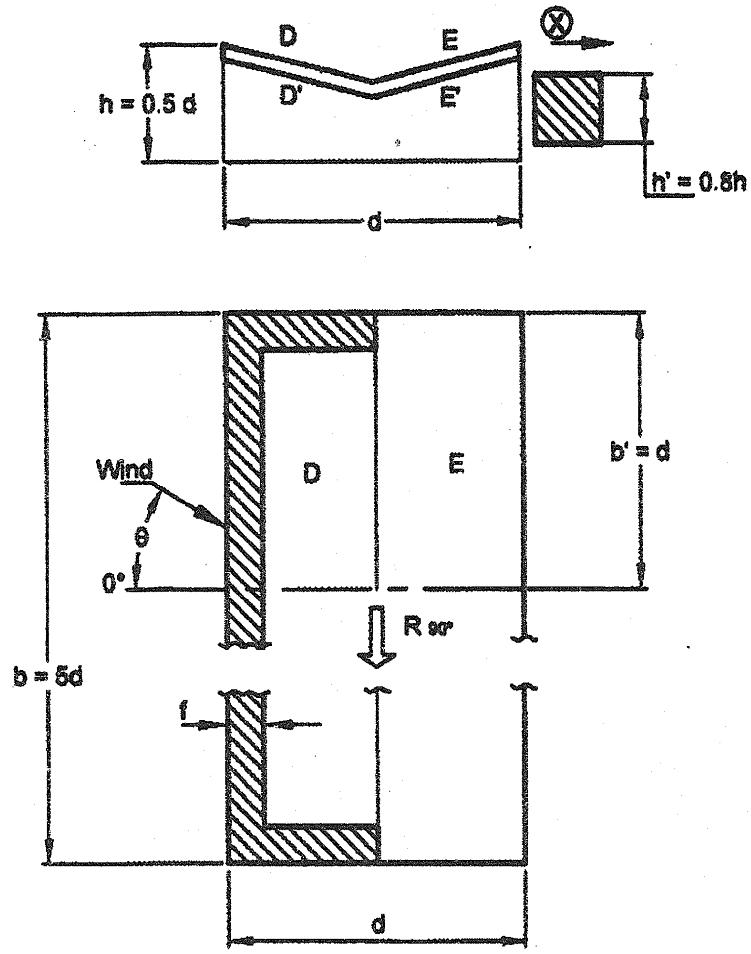
$\theta = 90°$, *D, D', E, E'* part length.

b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p			
	D	*D'*	*E*	*E'*
0°	+ 0.3	- 0.7	+ 0.2	- 0.9
45°	0	- 0.2	+ 0.1	- 0.3
90°	- 0.1	0.1	- 0.1	+ 0.1
For all value of θ	For *f* : C_p Top = 0.4, C_p bottom = - 1.5 Tangentially acting friction : $R_{90°} = 0.1\, p_d\, bd$			

Table 15 Pressure Coefficients (Top and Bottom) for Troughed Free Roofs, α = 10° with Effects of Train or Stored Materials

(*Clause* 7.3.3.3)

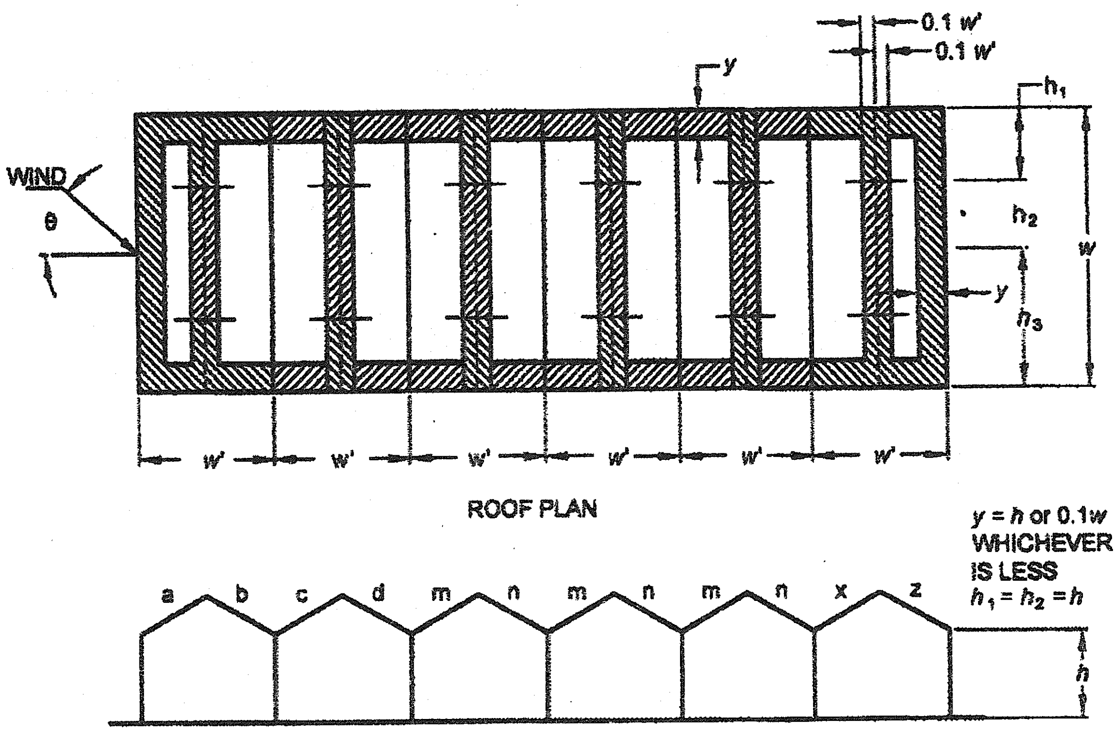


Roof slope α = 10°
Effects of trains or stored materials.
θ = 0°- 45°, or 135° - 180°, *D, D', E, E'* full length.
θ = 90°, *D, D', E, E'* part length.
b', thereafter C_p = 0

<table>
<tr><th rowspan="2">θ</th><th colspan="4">PRESSURE COEFFICIENTS, C_p</th></tr>
<tr><th>D</th><th>D'</th><th>E</th><th>E'</th></tr>
<tr><td>0°
45°
90°
180°</td><td>- 0.7
- 0.4
- 0.1
- 0.4</td><td>+ 0.8
+ 0.3
+ 0.1
- 0.2</td><td>- 0.6
- 0.2
- 0.1
- 0.6</td><td>+ 0.6
+ 0.2
+ 0.1
- 0.3</td></tr>
<tr><td>For all value of θ</td><td colspan="4">For f : C_p Top = -1.1, C_p bottom = 0.9
Tengentially acting friction : $R_{90°}$ = 0.1 p_d bd</td></tr>
</table>

Table 16 External Pressure Coefficients (C_{pe}) for Pitched Roofs of Multispan Buildings (All Spans Equal) with $h < w'$

(*Clause* 7.3.3.4)



SECTION

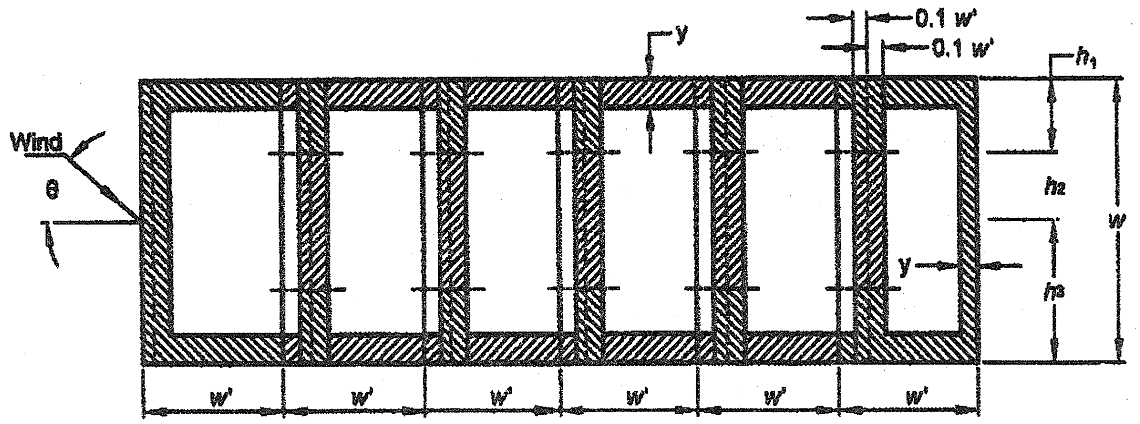
ROOF ANGLE	WIND ANGLE	FIRST SPAN		FIRST INTERME-DIATE SPAN		OTHER INTERME-DIATE SPANS		END SPAN		LOCAL COEFFICIENT	
α Degrees	θ Degrees	a	b	c	d	m	n	x	z	(cross-hatched)	(hatched)
5 10 20 30 45	0	-0.9 -1.1 -0.7 -0.2 +0.3	-0.6 -0.6 -0.6 -0.6 -0.6	-0.4 -0.4 -0.4 -0.4 -0.6	-0.3 -0.3 -0.3 -0.3 -0.4	-0.3 -0.3 -0.3 -0.2 -0.2	-0.3 -0.3 -0.3 -0.3 -0.4	-0.3 -0.3 -0.3 -0.2 -0.2	-0.3 -0.4 -0.5 -0.5 -0.5	-2.0	-1.5
DISTANCE											
ROOF ANGLE α DEGREES		WIND ANGLE θ DEGREES		h_1		h_2		h_3			
UP TO 45		90		-0.6		-0.6		-0.2			

Frictional drag : When wind angle θ = 0°, horizontal forces due to frictional drag are allowed for in the above values, and When wind angle θ = 90°, allow for frictional drag in accordance with 7.4.1

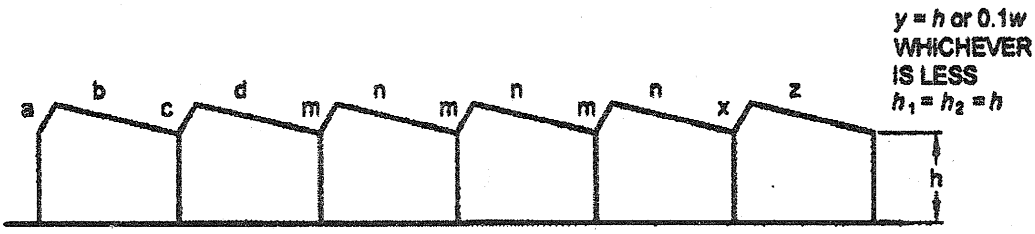
NOTE — Evidence on these buidings is fragmentary and any departure from the cases given should be investigated separately.

Table 17 External Pressure Coefficients (C_{pe}) for Saw Tooth Roofs of Multispan Buildings (All Spans Equal) with $h < w'$

(*Clause* 7.3.3.4)



ROOF PLAN



SECTION

WIND ANGLE	FIRST SPAN		FIRST INTERME-DIATE SPAN		OTHER INTERME-DIATE SPANS		END SPAN		LOCAL COEFFICIENT	
θ Degrees	a	b	c	d	m	n	x	z	(cross-hatched, dense)	(hatched)
0	+0.6	-0.7	-0.7	-0.4	-0.3	-0.2	-0.1	-0.3	-2.0	-1.5
180	-0.5	-0.3	-0.3	-0.3	-0.4	-0.6	-0.6	-0.1		

DISTANCE

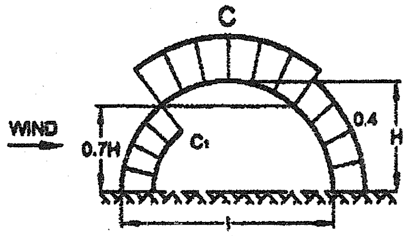
WIND ANGLE θ DEGREES	h_1	h_2	h_3
90	-0.8	-0.6	-0.2
270	Similar to 90°, h_1, h_2, h_3, are needed to be reckoned from the windword edge in the same order		

Frictional drag : When wing angle θ = 0°, horizontal forces due to frictional drag are allowed for in the above values, and When wind angle θ = 90°, allow for frictional drag in accordance with 7.4.1.

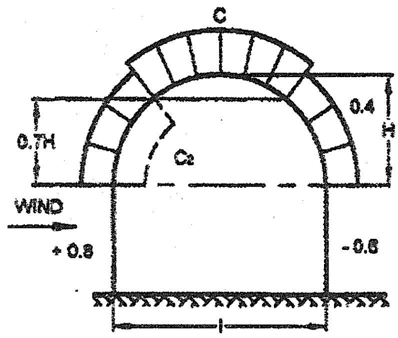
NOTE — Evidence on these buidings is fragmentary and any departure from the cases given should be investigated separately.

Table 18 External Pressure Coefficients (C_{pe}) for Curved Roofs

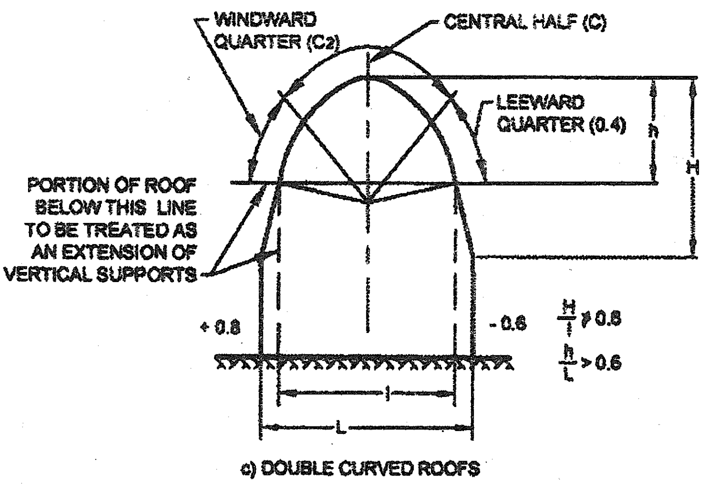
(*Clause* 7.3.3.6)



a) ROOF SPRINGING FROM GROUND LEVEL



b) ROOF ON ELEVATED STRUCTURE



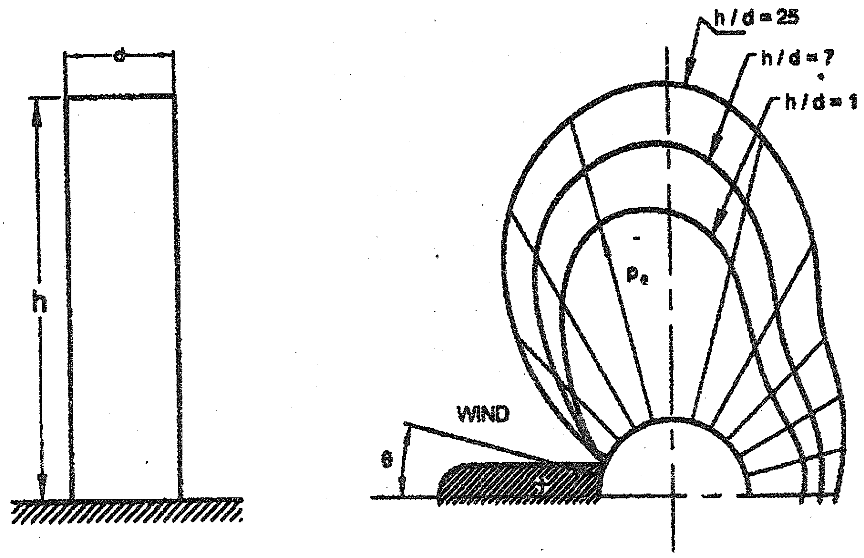
c) DOUBLE CURVED ROOFS

VALUES OF C, C_1 and C_2

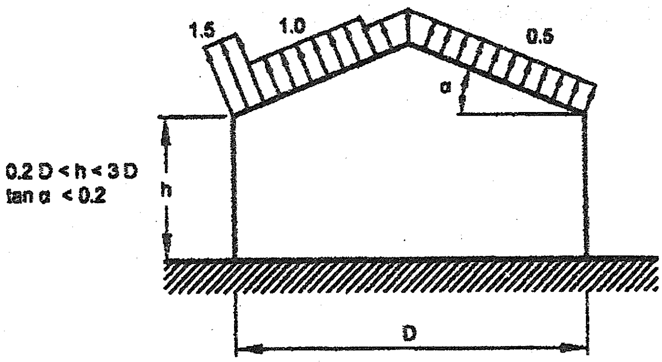
H/l	C	C_1	C_2
0.1	- 0.8	+ 0.1	+ 0.05
0.2	- 0.9	+ 0.3	+0.1
0.3	- 1.0	+ 0.4	+0.15
0.4	- 1.1	+ 0.6	-
0.5	- 1.2	+ 0.7	-

NOTE — When the wind is blowing normal to gable ends, C_{pe} may be taken as equal to –0.7 for the full width of the roof over a length of $l/2$ from the gable ends and –0.5 for the remaining portion.

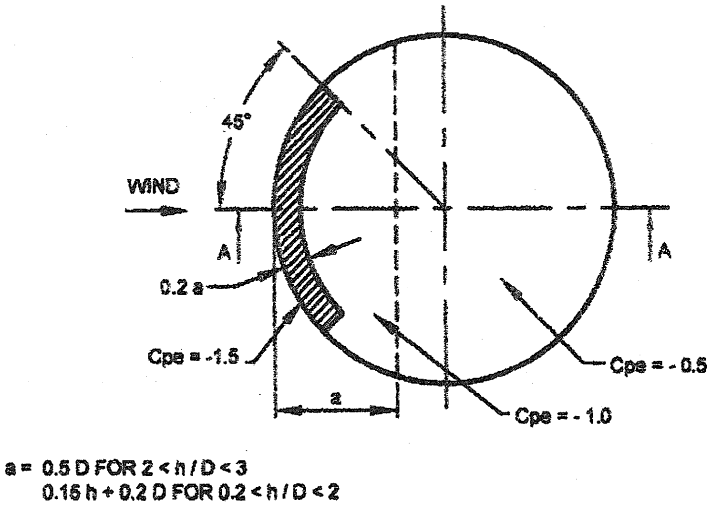
Table 19 External Pressure Coefficients Around Cylindrical Structures
(*Clause* 7.3.3.7)



POSITION OF PERIPHERY, θ IN DEGREES	PRESSURE COEFFICIENTS C_{pe}		
	$h/D = 25$	$h/D = 7$	$h/D = 1$
0	1.0	1.0	1.0
15	0.8	0.8	0.8
30	0.1	0.1	0.1
45	- 0.9	- 0.8	- 0.7
60	- 1.9	- 1.7	- 1.2
75	- 2.5	- 2.2	- 1.6
90	- 2.6	- 2.2	- 1.7
105	- 1.9	- 1.7	- 1.2
120	- 0.9	- 0.8	- 0.7
135	- 0.7	- 0.6	- 0.5
150	- 0.6	- 0.5	- 0.4
165	- 0.6	- 0.5	- 0.4
180	- 0.6	- 0.5	- 0.4



SECTION AA



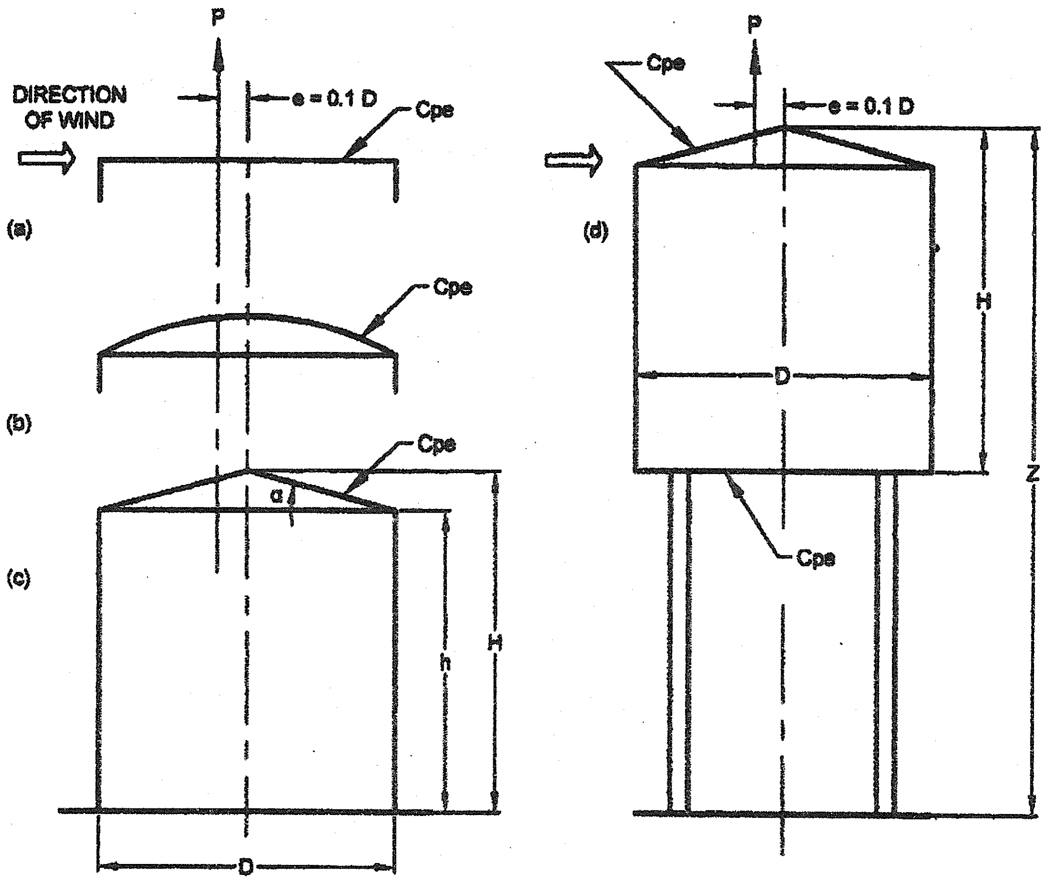
PLAN

[For force coefficient corresponding to shell portion (See Table 25)]

FIG. 3 EXTERNAL PRESSURE COEFFICIENTS ON THE UPPER ROOF SURFACE OF CYCLINDRICAL STRUCTURES STANDING ON THE GROUND

Table 20 External Pressure Coefficients for Roofs and Bottoms of Cylindrical Structures

(*Clause* 7.3.3.8)



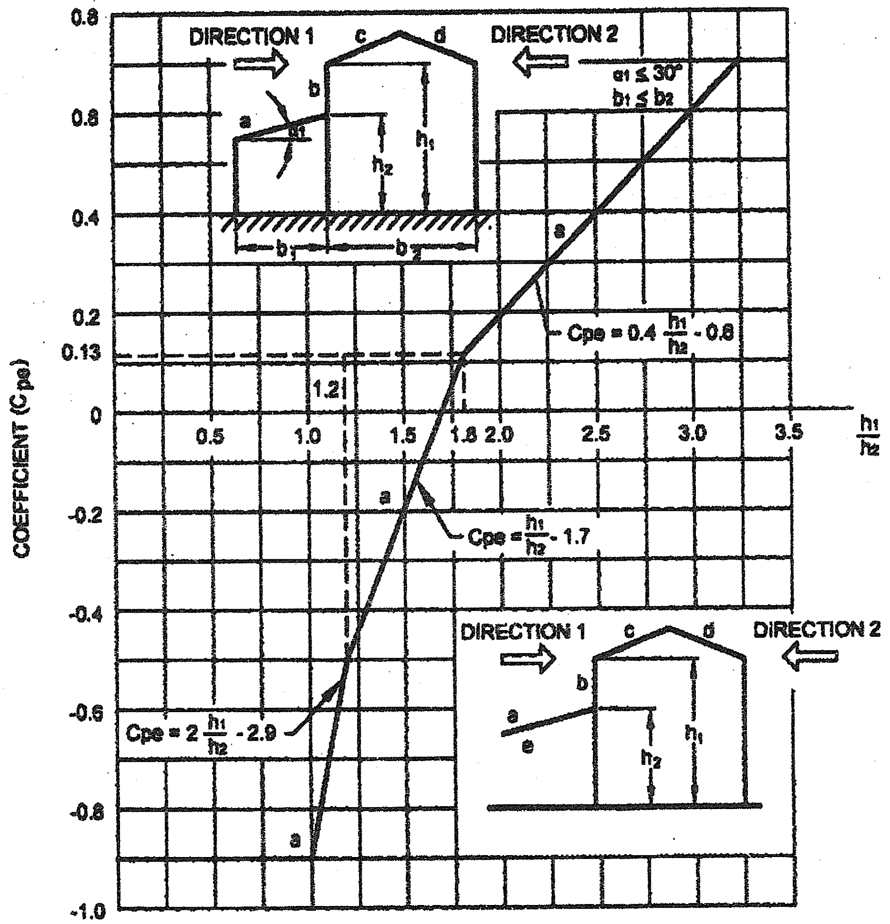
COEFFICIENTS OF EXTERNAL PRESSURE C_{pe}				
STRUCTURE ACCORDING TO SHAPE				
a, b and c		d		
H / D	ROOF	(z / H) - 1	ROOF	BOTTOM
0.5	- 0.65	1.00	- 0.75	- 0.8
1.00	- 1.00	1.25	- 0.75	- 0.7
2.00	- 1.00	1.50	- 0.75	- 0.6

Total force acting on the roof of the structure, $P = 0.785\ D^2\ (C_{pi} - C_{pe})\ p_d$

The resultant of P lies eccentrically, $e = 0.1D$

Table 21 External Pressure Coefficients (C_{pe}) for Combined Roofs

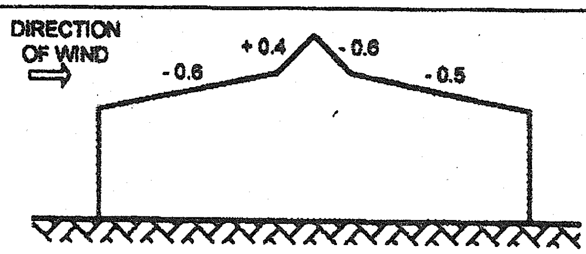
(*Clause* 7.3.3.9)

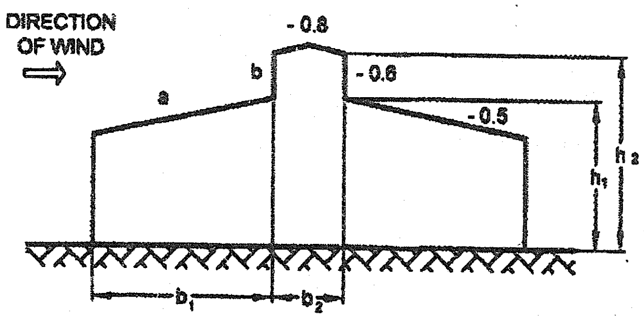


VALUES OF COEFFICIENTS (C_{pe})		
PORTION	DIRECTION 1	DIRECTION 2
a	FROM THE DIAGRAM	- 0.4
b	$C_{pe} = -0.5, \frac{h_1}{h_2} \leq 1.5$ $C_{pe} = +0.7; \frac{h_1}{h_2} > 1.5$	
c and d	See Table 6	
e	See Clause 6.3.3.5	

Table 22 External Pressure Coefficients (C_{pe}) for Roofs with a Sky Light

(*Clause* 7.3.3.10)





b) ROOFS WITH A SKY LIGHT

VALUES OF COEFFICIENTS (C_{pe})			
PORTION	$b_1 > b_2$		$b_1 \leq b_2$
	a	*b*	*a* and *b*
Cpe	- 0.6	+ 0.7	See Table for combined roofs

7.4 *Force Coefficients*

The value of force coefficients (C_f) apply to a building or structure as a whole, and when multiplied by the effective frontal area A_e of the building or structure and design wind pressure, p_d gives the total wind load (F) on that particular building or structure.

$$F = C_f A_e p_d$$

where F is the force acting in a direction specified in the respective tables and C_f is the force coefficient for the building.

NOTES

1 The value of the force coefficient differs for the wind acting on different faces of a building or structure. In order to determine the critical load, the total wind load should be calculated for each wind direction.

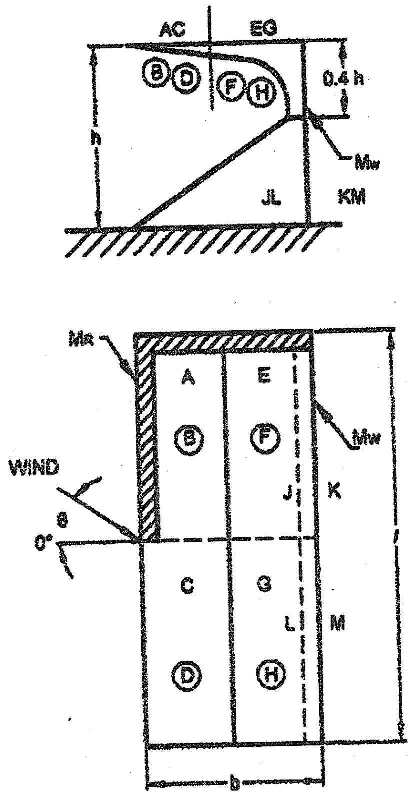
2 If surface design pressure varies with height, the surface area of the building/structure may be sub-divided so that specified pressures are taken over appropriate areas.

3 In tapered buildings/structures, the force coefficients shall be applied after sub-dividing the building/structure into suitable number of strips and the load on each strip calculated individually, taking the area of each strip as A_e.

4 For force coefficients for structures not covered above reference may be made specialist literature on the subject or advice may be sought from specialist in the subject.

Table 23 Pressure Coefficients at Top and Bottom Roof of Grand Stands Open Three Sides (Roof Angle Upto 5°)

(*Clause* 7.3.3.11)

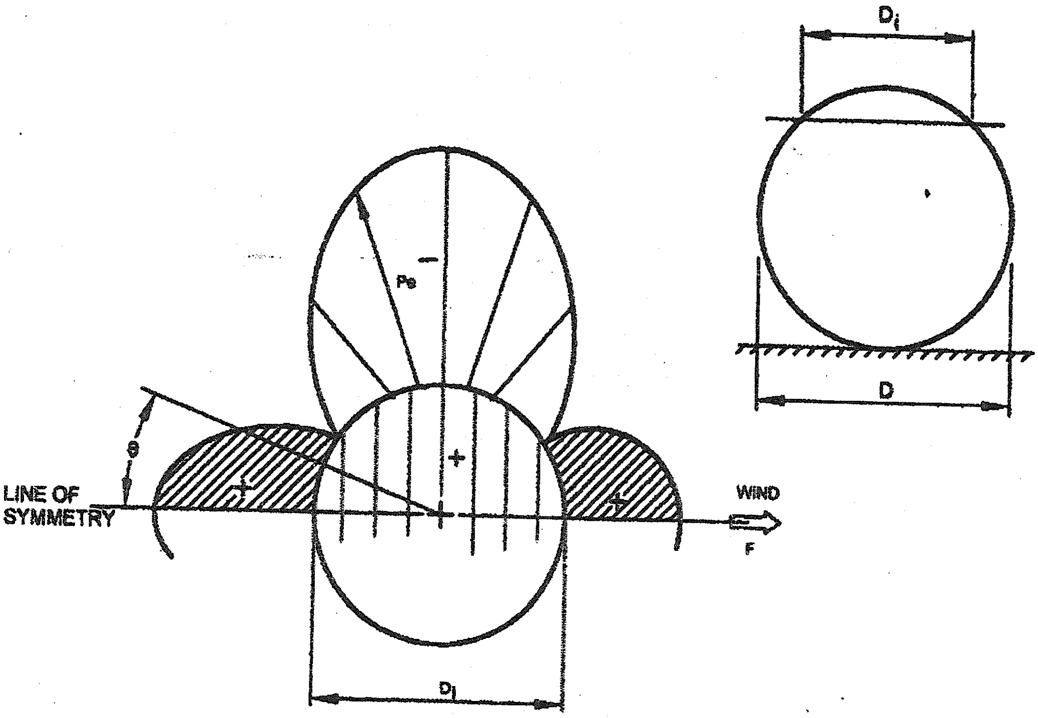


(Shaded area to scale)

FRONT AND BACK OF WALL				
θ	*J*	*K*	*L*	*M*
0°	+ 0.9	- 0.5	+ 0.9	- 0.5
45°	+ 0.8	- 0.6	+ 0.4	- 0.4
135°	- 1.1	+ 0.6	- 1.0	+ 0.4
180°	- 0.3	+ 0.9	- 0.3	+ 0.9
60°	*Mw* - Cp of K = - 1.0			
60°	*Mw* - Cp of J = + 1.0			

TOP AND BOTTOM ROOF								
θ	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
0°	- 1.0	+ 0.9	- 1.0	+ 0.9	- 0.7	+ 0.9	+ 0.7	+ 0.9
45°	- 1.0	+ 0.7	- 0.7	+ 0.4	- 0.5	+ 0.8	- 0.5	+ 0.3
135°	- 0.4	- 1.1	- 0.7	- 1.0	- 0.9	- 1.1	- 0.9	- 1.0
180°	- 0.6	- 0.3	- 0.6	- 0.3	- 0.6	- 0.3	- 0.6	- 0.3
45°	'M_R' - Cp (top) = - 2.0							
45°	'M_R' - Cp (bottom) = + 1.0							

Table 24 External Pressure Distribution Coefficients Around Spherical Structures
(*Clause* 7.3.3.12)



POSITION OF PERIPHERY, θ IN DEGREES	Cpe
0	+ 1.0
15	+ 0.9
30	+ 0.5
45	- 0.1
60	- 0.7
75	- 1.1
90	- 1.2
105	- 1.0
120	- 0.6
135	- 0.2
150	+ 0.1
165	+ 0.3
180	+ 0.4

7.4.1 *Frictional Drag*

In certain buildings of special shape, a force due to frictional drag shall be taken into account in addition to those loads specified in 7.3. For rectangular clad buildings, this addition is necessary only where the ratio d/h or d/b is more than 4. The frictional drag force, F', in the direction of the wind is given by the following formulae:

a) If $h \leq b$, $F' = C_f'(d-4h)\,bp_d + C_f'(d-4b)\,2h\,p_d$, and

b) If $h > b$, $F' = C_f'(d-4b)\,bp_d + C_f'(d-4b)\,2h\,p_d$

The first term in each case gives the drag on the roof and the second on the walls. The value of C_f' has the following value:

1) $C_f' = 0.01$ for smooth surfaces without corrugations or ribs across the wind direction,
2) $C_f' = 0.02$ for surfaces with corrugations across the wind direction, and
3) $C_f' = 0.04$ for surfaces with ribs across the wind direction.

For other buildings, the frictional drag has been indicated, where necessary, in the tables of pressure coefficients and force coefficients.

7.4.2 *Force Coefficients for Clad Buildings*

7.4.2.1 *Clad buildings of uniform section*

The overall force coefficients for rectangular clad buildings of uniform section with flat roofs in uniform flow shall be as given in Fig. 4 and for other clad buildings of uniform section (without projections, except where otherwise shown) shall be as given in Table 25.

NOTE — Structures that are in the supercritical flow regime, because of their size and design wind velocity, may need further calculation to ensure that the greatest loads do not occur at some wind speed below the maximum when the flow will be sub critical. The coefficients are for buildings without projections, except where otherwise shown.

In Table 25, $\bar{V}_d\, b$ is used as an indication of the airflow regime.

7.4.2.2 *Buildings of circular shapes*

Force coefficients for buildings of circular cross-section shapes shall be as given in Table 25. However more precise estimation of force coefficients for circular shapes of infinite length can be obtained from Fig. 5

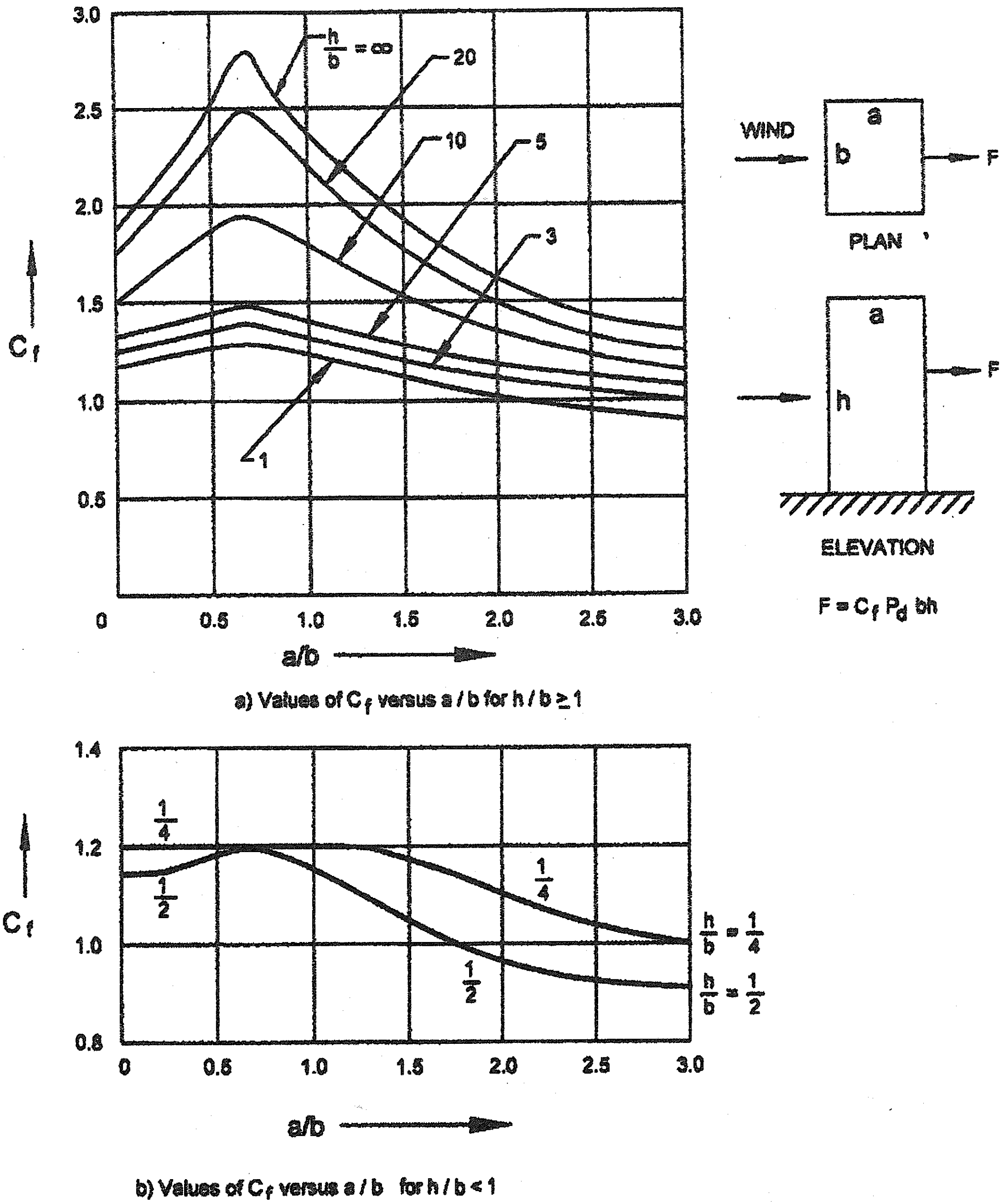


FIG. 4 FORCE COEFFICIENT FOR RECTANGULAR CLAD BUILDING IN UNIFORM FLOW

Table 25 Force Coefficients C_f for Clad Buildings of Uniform Section
(Acting in the Direction of Wind)
(*Clause* 7.4.2.2)

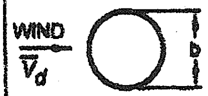
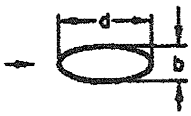
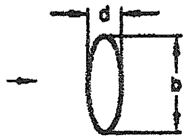
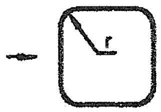
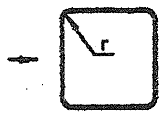
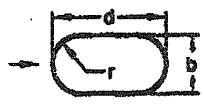
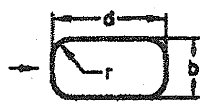
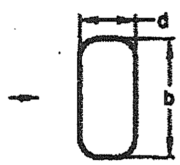
PLAN SHAPE	$\overline{V}_d b$ m^2/s	C_f FOR HEIGHT / BREADTH RATIO						
		UPTO 1/2	1	2	5	10	20	∞
 See also Appendix D	ALL SURFACES < 6 ROUGH or WITH PROJECTION ≥ 6	0.7	0.7	0.7	0.8	0.9	1.0	1.2
	SMOOTH ≥ 6	0.5	0.5	0.5	0.5	0.5	0.6	0.6
 Ellipse b/d = 1/2	< 10	0.5	0.5	0.5	0.5	0.6	0.6	0.7
	≥ 10	0.2	0.2	0.2	0.2	0.2	0.2	0.2
 Ellipse b/d = 2	< 8	0.8	0.8	0.9	1.0	1.1	1.3	1.7
	≥ 8	0.8	0.8	0.9	1.0	1.1	1.3	1.5
 b/d = 1 r/b = 1/3	< 4	0.6	0.6	0.6	0.7	0.8	0.8	1.0
	≥ 4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
 b/d = 1 r/b = 1/6	< 10	0.7	0.8	0.8	0.9	1.0	1.0	1.3
	≥ 10	0.5	0.5	0.5	0.5	0.6	0.6	0.6
 b/d = 1/2 r/b = 1/2	< 3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
	≥ 3	0.2	0.2	0.2	0.2	0.3	0.3	0.3
 b/d = 1/2 r/b = 1/6	All values	0.5	0.5	0.5	0.5	0.6	0.6	0.7
 b/d = 2 r/b = 1/12	All values	0.9	0.9	1.0	1.1	1.2	1.5	1.9

Table 25 — (*Continued*)

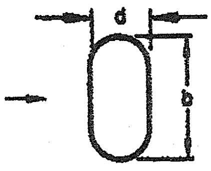
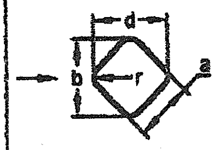
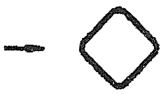
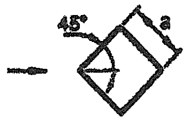
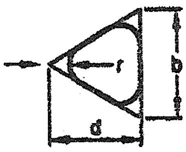
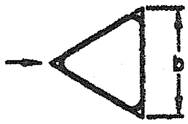
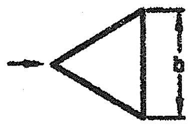
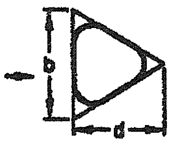
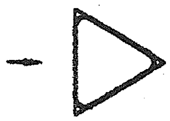
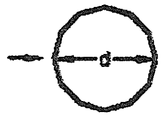
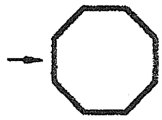
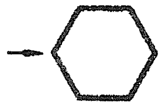
PLAN SHAPE	$V_d\,b$ m^2/s	C_f FOR HEIGHT / BREADTH RATIO						
		UPTO 1/2	1	2	5	10	20	∞
 b/d = 2, r/b = 1/4	< 6	0.7	0.8	0.8	0.9	1.0	1.2	1.6
	≥ 6	0.5	0.5	0.5	0.5	0.5	0.6	0.6
 r/a = 1/3	< 10	0.8	0.8	0.9	1.0	1.1	1.3	1.5
	≥ 10	0.5	0.5	0.5	0.5	0.6	0.6	0.6
 r/a = 1/12	All values	0.9	0.9	0.9	1.1	1.2	1.3	1.6
 r/a = 1/48	All values	0.9	0.9	0.9	1.1	1.2	1.3	1.6
 r/b = 1/4	< 11	0.7	0.7	0.7	0.8	0.9	1.0	1.2
	≥ 11	0.4	0.4	0.4	0.4	0.5	0.5	0.5
 r/b = 1/12	All values	0.8	0.8	0.8	1.0	1.1	1.2	1.4
 r/b = 1/48	All values	0.7	0.7	0.8	0.9	1.0	1.1	1.3
 r/b = 1/4	< 8	0.7	0.7	0.8	0.9	1.0	1.1	1.3
	≤ 8	0.4	0.4	0.4	0.4	0.5	0.6	0.6

Table 25 — (*Concluded*)

PLAN SHAPE	$\bar{V}_d b$ m^2/s	C_f FOR HEIGHT / BREADTH RATIO						
		UPTO 1/2	1	2	5	10	20	∞
 1/48 < r/b < 1/12	All values	1.2	1.2	1.2	1.4	1.6	1.7	2.1
 12 SIDED POLYGON	< 12	0.7	0.7	0.8	0.9	1.0	1.1	1.3
	≥ 12	0.7	0.7	0.7	0.7	0.8	0.9	1.1
 OCTAGON	All values	1.0	1.0	1.1	1.2	1.2	1.3	1.4
 HEXAGON	All values	1.0	1.1	1.2	1.3	1.4	1.4	1.5

taking into account the average height of surface roughness ε. When the length is finite the values obtained from Fig. 5 shall be reduced by the multiplication factor K (*see* Table 28 and Annex D).

7.4.2.3 *Free standing walls and hoardings*

Force coefficients for free standing walls and hoardings shall be as given in Table 26.

To allow for oblique winds, the design shall also be checked for net pressure normal to the surface varying linearly from a maximum of 1.7 C_f at the windward edge to 0.44 C_f at the leeward edge.

The wind load on appurtenances and supports for hoardings shall be accounted for separately by using the appropriate net pressure coefficients. Allowance shall be made for shielding effects of one element on another.

7.4.2.4. *Solid circular shapes mounted on a surface*

The force coefficients for solid circular shapes mounted on a surface shall be as given in Table 27.

7.4.3 *Force Coefficients for Unclad Buildings*

7.4.3.1 This section applies to permanently unclad buildings and to frameworks of buildings while temporarily unclad. In the case of buildings whose surfaces are well-rounded, such as those with elliptic, circular or oval cross-sections, the total force can be more at a wind speed much less than maximum due to transition in the nature of boundary layer on them. Although this phenomenon is well known in the case of circular cylinders, the same phenomenon exists in the case of many other well-rounded structures, and this possibility must be checked.

7.4.3.2 *Individual members*

a) The force coefficient given in Table 29 refers to members of infinite length. For members of finite length, the coefficients should be multiplied by a factor K that depends on the ratio l/b where l is the length of the member and b is the width across the direction of wind. Table 28 gives the required values of K. The following special cases must be noted while estimating K.

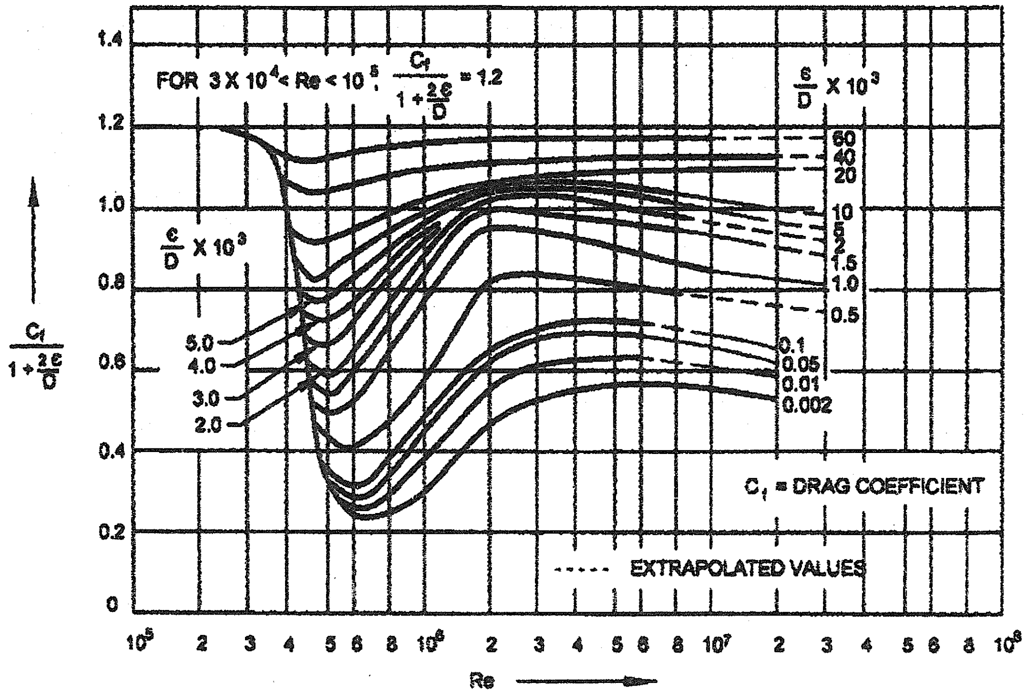
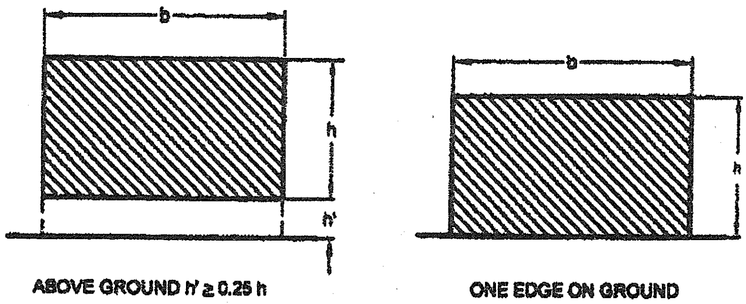


FIG. 5 VARIATION OF $\frac{C_f}{1+\frac{2\varepsilon}{D}}$ WITH $R_e > 3 \times 10^4$ FOR CIRCULAR SECTIONS

Table 26 Force Coefficients for Low Walls or Hoardings (< 15m High)
(*Clause* 7.4.2.2)



(WIND NORMAL TO FACE)

WIDTH TO HEIGHT RATIO, b/h		DRAG COEFFICIENT C_f
WALL ABOVE GROUND	WALL ON GROUND	
FROM 0.5 TO 6	FROM 1 TO 12	1.2
10	20	1.3
16	32	1.4
20	40	1.5
40	80	1.75
60	120	1.8
80 OR MORE	160 OR MORE	2.0

1) when any member abuts on to a plate or wall in such a way that free flow of air around that end of the member is prevented, then the ratio of l/b shall be doubled for the purpose of determining K; and
2) when both ends of a member are so obstructed, the ratio shall be taken as infinity for the purpose of determining K.

b) *Flat-sided members* — Force coefficients for wind normal to the longitudinal axis of flat-sided structural members shall be as given in Table 29.

The force coefficients are given for two mutually perpendicular directions relative to a reference axis on the structural member. They are denoted by C_{fn} and C_{ft} and give the forces normal and transverse respectively, to the reference plane as shown in Table 29.

Table 27 Force Coefficients for Solid Shapes Mounted on a Surface
(*Clause* 7.4.2.4)

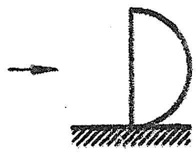
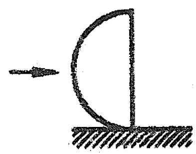
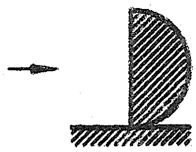
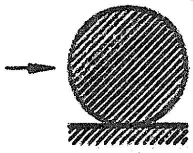
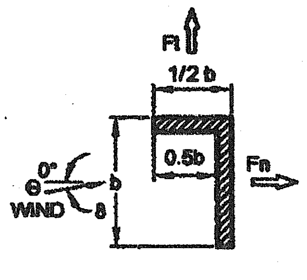
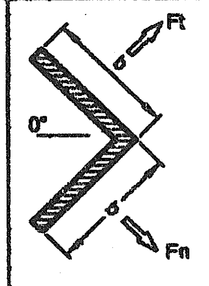
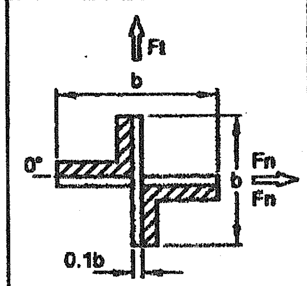
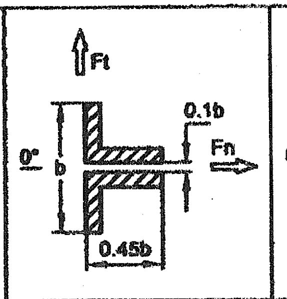
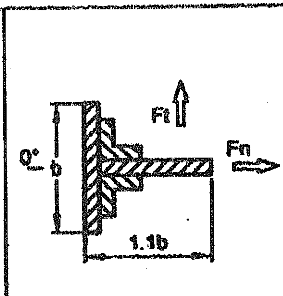
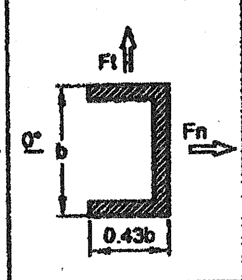
SIDE ELEVATION	DESCRIPTION OF SHAPE	C_f
	CIRCULAR DISC	1.2
	HEMISPHERICAL BOWL	1.4
	HEMISPHERICAL BOWL	0.4
	HEMISPHERICAL SOLID	1.2
	SPHERICAL SOLID	0.5 FOR $V_z D < 7$ 0.2 FOR $V_z D \geq 7$

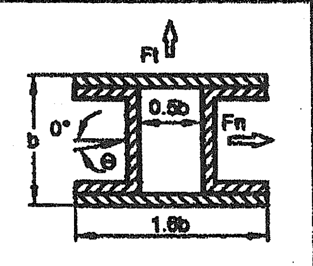
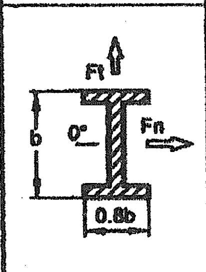
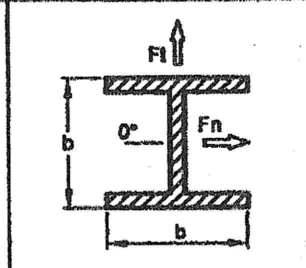
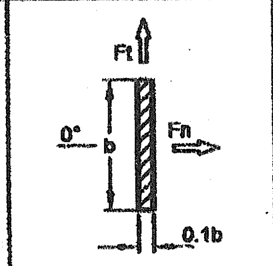
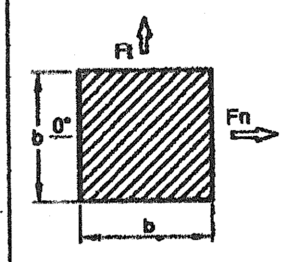
Table 28 Reduction Factor K for Individual Members
[(*Clauses* 7.4.2.2, 7.4.3.2(a)]

Sl No.	l/b or l/D	2	5	10	20	40	50	100	∞
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Circular cylinder, subcritical flow	0.58	0.62	0.68	0.74	0.82	0.87	0.98	1.00
ii)	Circular cylinder, supercritical flow ($D\bar{V}_z \geq 6 m^2/s$)	0.80	0.80	0.82	0.90	0.98	0.99	1.00	1.00
iii)	For plate perpendicular to wind ($b\bar{V}_z \geq 6 m^2/s$)	0.62	0.66	0.69	0.81	0.87	0.90	0.95	1.00

Table 29 Force Coefficients C_f for Individual Structural Members of Infinite Length

[*Clause* 7.4.3.2(b)]

												
θ DEGREE	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}
0	+ 1.9	+ 0.95	+ 1.8	+ 1.8	+ 1.75	+ 0.1	+ 1.6	0	+ 2.0	0	+ 2.05	0
45	+ 1.8	+ 0.8	+ 2.1	+ 1.8	+ 0.85	+ 0.85	+ 1.5	- 0.1	+ 1.2	+ 0.9	+ 1.85	+ 0.6
90	+ 2.0	+ 1.7	- 1.9	- 1.0	+ 0.1	+ 1.75	- 0.95	+ 0.7	- 1.6	+ 2.15	0	+ 0.6
135	- 1.8	- 0.1	- 2.0	+ 0.3	- 0.75	+ 0.75	- 0.5	+ 1.05	- 1.1	+ 2.4	- 1.6	+ 0.4
180	- 2.0	+ 0.1	- 1.4	- 1.4	- 1.75	- 0.1	- 1.5	0	- 1.7	+ 2.1	- 1.8	0

										
θ DEGREE	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}
0	+ 1.4	0	+ 2.05	0	+ 1.6	0	+ 2.0	0	+ 2.0	0
45	+ 1.2	+ 1.6	+ 1.95	+ 0.6	+ 1.5	+ 1.5	+ 1.8	+ 0.1	+ 1.55	+ 1.55
90	0	+ 2.2	+ 0.5	+ 0.9	0	+ 1.9	0	+ 0.1	0	+ 2.0

Normal force, $F_n = (C_{fn} p_d K)/b$

Transverse force, $F_t = (C_{ft} p_d K)/b$

c) *Circular sections* — Force coefficients for members of circular section shall be as given in Table 25 *see* also Annex D.

d) Force coefficients for wires and cables shall be as given in Table 30 according to the diameter (D), the design wind speed (V_d) and the surface roughness.

7.4.3.3 *Single frames*

Force coefficients for a single frame having either,

a) all flat sided members; or
b) all circular members in which all the members of the frame have either:
   1) $D \bar{V}_d$ less than 6 m²/s, or
   2) $D \bar{V}_d$ more than or equal to 6 m²/s,

shall be as given in Table 31 according to the type of the member, the diameter (D), the design hourly mean wind speed ($\bar{V}_d$) and the solidity ratio (Φ).

Force coefficients for a single frame not complying with the above requirements shall be calculated as follows:

$$C_f = \gamma C_{f_{super}} + (1-\gamma)\frac{A_{cir\,sub}}{A_{sub}} C_{f_{sub}} + (1-\gamma)\frac{A_{flat}}{A_{sub}} C_{f_{flat}}$$

where

$C_{f\,super}$ = force coefficient for the supercritical circular members as given in Table 31 or Annex D,

$C_{f\,sub}$ = force coefficient for subcritical circular members as given in Table 31or Annex D,

$C_{f\,flat}$ = force coefficient for the flat sided members as given in Table 31,

$A_{circ\,sub}$ = effective area of subcritical circular members,

A_{flat} = effective area of flat-sided members,

A_{sub} = $A_{circ\,sub} + A_{flat}$, and

γ = (Area of the frame in a supercritical flow)/ A_e

7.4.3.4 *Multiple frame buildings*

This section applies to structures having two or more parallel frames where the windward frames may have a shielding effect upon the frames to leeward side. The windward frame and any unshielded parts of other frames shall be calculated in accordance with 7.4.3.3, but the wind load on the parts of frames that are sheltered should be multiplied by a shielding factor which is dependent upon the solidity ratio of the windward frame, the types of members comprising the frame and the spac-ing ratio of the frames. The values of the shielding factors are given in Table 32.

Table 30 Force Coefficients for Wires and Cables (L/D = 100)
[*Clause* 7.4.3.2(d)]

Sl No.	Flow Regime	Force Coefficient, C_f for			
		Smooth Surface	Moderately Smooth Wire (Galvanized or Painted)	Fine Stranded Cables	Thick Stranded Cables
(1)	(2)	(3)	(4)	(5)	(6)
i)	$D \bar{V}_d < 6$ m²/s	1.2	1.2	1.2	1.3
ii)	$D \bar{V}_d \geq 6$ m²/s	0.5	0.7	0.9	1.1

Table 31 Force Coefficients for Single Frames
(*Clause* 7.4.3.3)

Solidity Ratio	Force Coefficient C_f for		
	Flat Sided Members	Circular sections	
		Subcritical Flow ($D\bar{V}_d$ < 6 m²/s)	Super Critical Flow (D $\bar{V}_d$6 m²/s)
(1)	(2)	(3)	(4)
0.1	1.9	1.2	0.7
02	1.8	1.2	0.8
0.3	1.7	1.2	0.8
0.4	1.7	1.1	0.8
0.5	1.6	1.1	0.8
0.75	1.6	1.5	1.4
1.00	2.0	2.0	2.0

NOTE — Linear interpolation between the values is permitted.

Table 32 Shielding Factor *H* for Multiple Frames
(*Clause* 7.4.3.4)

Effective Solidity Ratio Φ_e	Frame Spacing Ratio				
	< 0.5	1.0	2.0	4.0	> 8.0
(1)	(2)	(3)	(4)	(5)	(6)
0	1.0	1.0	1.0	1.0	1.0
0.1	0.9	1.0	1.0	1.0	1.0
0.2	0.8	0.9	1.0	1.0	1.0
0.3	0.7	0.8	1.0	1.0	1.0
0.4	0.6	0.7	1.0	1.0	1.0
0.5	0.5	0.6	0.9	1.0	1.0
0.7	0.3	0.6	0.8	0.9	1.0
1.0	0.3	0.6	0.6	0.8	1.0

NOTE — Linear interpolation between the values is permitted.

Where there are more than two frames of similar geometry and spacing, the wind load on the third and subsequent frames should be taken as equal to that on the second frame. The loads on the various frames shall be added to obtain total load on the structure.

a) The frame spacing ratio is equal to the centre to centre distance between the frames, beams or girders divided by the least overall dimension of the frames, beam or girder measured in a direction normal to the direction of wind. For triangular framed structures or rectangular framed structures diagonal to the wind, the spacing ratio should be calculated from the mean distance between the frames in the direction of the wind.

b) Effective solidity ratio, Φ_e:

$\Phi_e = \Phi$ for flat-sided members.

Φ_e is to be obtained from Fig. 6 for members of circular cross-sections.

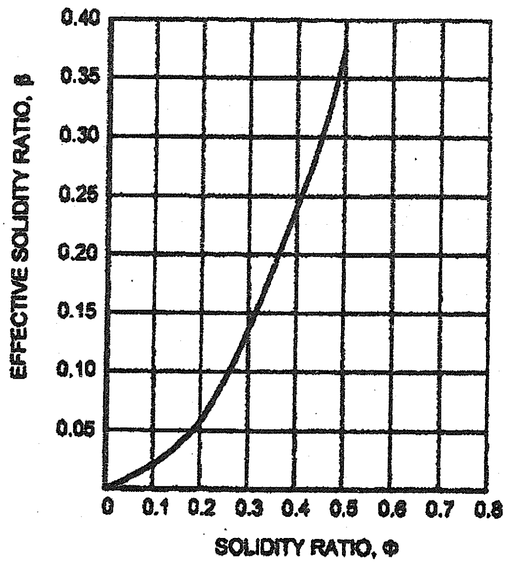


FIG. 6 EFFECTIVE SOLIDITY RATIO, FOR CIRCULAR SECTION MEMBERS

7.4.3.5 *Lattice towers*

a) Force coefficient for lattice towers of square or equilateral triangle section with flat-sided members for wind blowing against any face shall be as given in Table 33.

b) For square lattice towers with flat-sided members the maximum load, which occurs when the wind blows into a corner, shall be taken as 1.2 times the load for the wind blowing against a face.

c) For equilateral triangle lattice towers with flat-sided members, the load may be assumed to be constant for any inclination of wind to a face.

d) Force coefficients for lattice towers of square section with circular members, all in the same flow regime, may be as given in Table 34.

e) Force coefficients for lattice towers of equilateral-triangle section with circular members all in the same flow regime may be as given in Table 35.

7.4.3.6 *Tower appurtenances*

The wind loading on tower appurtenances, such as ladders, conduits, lights, elevators, etc, shall be calculated using appropriate net pressure coefficients

Table 33 Overall Force Coefficients for Towers Composed of Flat Sided Members
[*Clause* 7.4.3.5(a)]

Sl No.	Solidity Ratio Φ	Force Coefficient	
		Square Towers	Equilateral Triangular Towers
(1)	(2)	(3)	(4)
i)	< 0.1	3.8	3.1
ii)	0.2	3.3	2.7
iii)	0.3	2.8	2.3
iv)	0.4	2.3	1.9
v)	0.5	2.1	1.5

Table 34 Overall Force Coefficients for Square Towers Composed of Circular Members
[(*Clause* 7.4.3.5 (d)]

Sl No.	Solidity Ratio of Front Face Φ	Force Coefficient			
		Subcritical Flow ($D\,\bar{U}_0 < 6$ m²/s)		Supercritical Flow ($D\,\bar{U}_0 \geq 6$ m²/s)	
		Onto Face	Onto Corner	Onto Face	Onto Corner
(1)	(2)	(3)	(4)	(5)	(6)
i)	< 0.05	2.4	2.5	1.1	1.2
ii)	0.1	2.2	2.3	1.2	1.3
iii)	0.2	1.9	2.1	1.3	1.6
iv)	0.3	1.7	1.9	1.4	1.6
v)	0.4	1.6	1.9	1.4	1.6
vi)	0.5	1.4	1.9	1.4	1.6

for these elements. Allowance may be made for shielding effect from other elements.

8 INTERFERENCE EFFECTS

8.1 General

Wind interference is caused by modification in the wind characteristics produced by the obstruction caused by an object or a structure in the path of the wind. If such wind strikes another structure, the wind pressures usually get enhanced, though there can also be some shielding effect between two very closely spaced buildings/structures. The actual phenomenon is too complex to justify generalization of the wind forces/pressures produced due to interference which can only be ascertained by detailed wind tunnel/CFD studies. However, some guidance can be provided for the purpose of preliminary design. To account for the effect of interference, a wind interference factor (IF) has been introduced as a multiplying factor to be applied to the design wind pressure/force. Interference effects can be more significant for tall buildings. The interference factor is defined as the ratio between the enhanced pressure/force in the grouped configuration to the corresponding pressure/force in isolated configuration. Since the values of IF can vary considerably based on building geometry and location, the given values of IF are a kind of median values and are meant only for preliminary design estimates. The designer is advised that for assigning values of IF for final design particularly for tall buildings, specialist literature be consulted or a wind tunnel study carried out.

8.2 Roof of Low-Rise Buildings

Maximum increase in wind force on the roof due to interference from similar buildings in case of closely spaced low-rise buildings with flat roofs may be up to 25 percent for c/c distance (x) between the buildings of 5 times the dimension (b) of the interfering building normal to the direction of wind (*see* Fig. 7). Interference effect beyond 20b may be considered to be negligible. For intermediate spacing linear interpolation may be used.

8.3 Tall Buildings

Based on studies on tall rectangular buildings, Fig. 8 gives various zones of interference. The interference factor (IF), which needs to be considered as a multiplication factor for wind loads corresponding to

Table 35 Overall Force Coefficients for Equilateral Triangular Towers Composed of Circular Members
[*Clause* 7.4.3.5(e)]

Sl No.	Solidity Ratio of Front Face Φ	Force Coefficient	
		Subcritical Flow ($D\,\bar{U}_0 < 6$ m²/s) All wind Directions	Supercritical Flow ($D\,\bar{U}_0 \geq 6$ m²/s) All wind Directions
(1)	(2)	(3)	(4)
i)	< 0.05	1.8	0.8
ii)	0.1	1.7	0.8
iii)	0.2	1.6	1.1
iv)	0.3	1.5	1.1
v)	0.4	1.5	1.1
vi)	0.5	1.4	1.2

isolated building, may be assumed as follows, for preliminary estimate of the wind loads under interference caused by another interfering tall building of same or more height located at different zones Z1 to Z4 as shown in Fig. 8:

Zone	Z1	Z2	Z3	Z4
IF	1.35	1.25	1.15	1.07

The interference effect due to buildings of height less than one-third of the height of the building under consideration may be considered to be negligible while for interference from a building of intermediate height, linear interpolation may be used between one-third and full height.

9 DYNAMIC EFFECTS

9.1 General

Flexible slender structures and structural elements shall be investigated to ascertain the importance of wind induced oscillations or excitations in along wind and across wind directions.

In general, the following guidelines may be used for examining the problems of wind-induced oscillations.

a) Buildings and closed structures with a height to minimum lateral dimension ratio of more than about 5.0, or

b) Buildings and structures whose natural frequency in the first mode is less than 1.0 Hz.

Any building or structure which satisfies either of the above two criteria shall be examined for dynamic effects of wind.

NOTES

1 The fundamental time period (T) may either be established by experimental observations on similar buildings or calculated by any rational method of analysis. In the absence of such data, T may be determined as follows for multi-storied buildings:

a) For moment resistant frames without bracings or shear walls resisting the lateral loads,

$T = 0.1\ n$

where

n = number of storeys including basement storeys; and

b) for all others

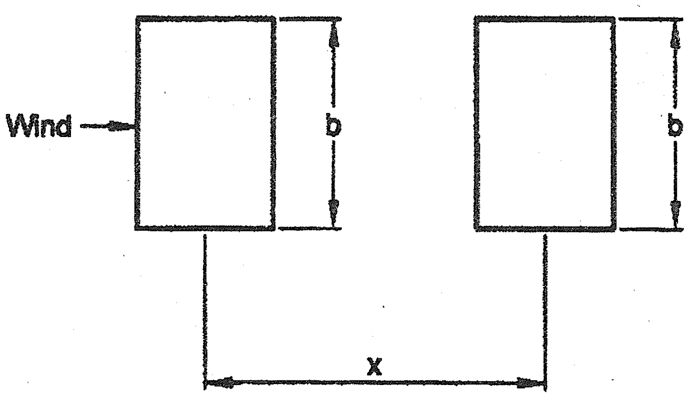
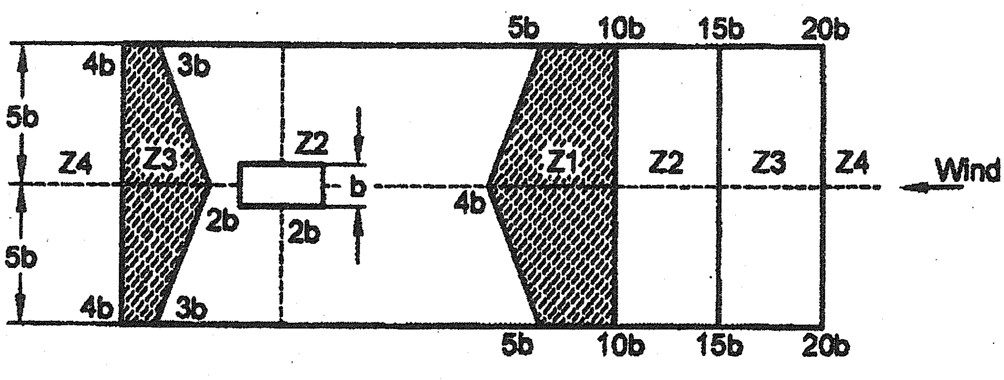


FIG. 7 LOW-RISE BUILDINGS IN TANDEM CAUSING INTERFERENCE EFFECT



Z1 - Zone of high interference
Z2 - Zone of moderate interference
Z3 - Zone of low interference
Z4 - Zone of insignificant interference

FIG. 8 INTERFERENCE ZONES FOR TALL RECTANGULAR BUILDINGS OF SAME OR GREATER HEIGHT (CLAUSE 7.3)

$$T = \frac{0.09H}{\sqrt{d}}$$

where

H = total height of the main structures of the building, in m; and

d = maximum base dimension of building in meters in a direction parallel to the applied wind force.

2 If preliminary studies indicate that wind-induced oscillations are likely to be significant, investigations should be pursued with the aid of analytical methods or if necessary, by means of wind tunnel tests on models.

3 Across-wind motions may be due to lateral gustiness of the wind. unsteady wake flow (for example, vortex shedding), negative aerodynamic damping or due to a combination of these effects. These cross-wind motions may become critical in the design of tall buildings/structures.

4 Motions in the direction of wind (known also as buffeting) are caused by fluctuating wind force associated with gust. The excitation depends on gust energy available at the resonant frequency.

5 The eddies shed from an upstream body may intensify motion in the direction of the wind and may also affect cross-wind motion.

6 The designer should also be aware of the following three forms of wind-induced motion which are characterized by increasing amplitude of oscillation with the increase of wind speed.

i) Galloping — Galloping is transverse oscillations of some structures due to the development of aerodynamic forces which are in phase with the motion. It is characterized by the progressively increasing amplitude of transverse vibration with increase of wind speed. The cross-sections which are particularly prone to this type of excitation include the following:

   1) All structures with non-circular cross-sections, such as triangular, square, polygons, as well as angles, crosses, and T sections.

   2) Twisted cables and cables with ice encrustations.

ii) Flutter — Flutter is unstable oscillatory motion of a structure due to coupling between aerodynamic force and elastic deformation of the structure. Perhaps the most common form is oscillatory motion due to combined bending and torsion. Although oscillatory motion in each degree of freedom may be damped, instability can set in due to energy transfer from one mode of oscillation to another and the structure is seen to execute sustained or divergent oscillations with a type of motion which is a combination of the individual modes of vibration. Such energy transfer takes place when the natural frequencies of modes taken individually are close to each other (ratio being typically less than 2.0). Flutter can set in at wind speeds much less than those required for exciting the individual modes of motion. Long span suspension bridge decks or any member of a structure with large values of d/t (where d is the length of the member and t is its dimension parallel to wind stream) are prone to low speed flutter. Wind tunnel testing is required to determine critical flutter speeds and the likely structural response. Other types of flutter are single degree of freedom stall flutter, torsional flutter, etc.

iii) Ovalling — Thin walled structures with open ends at one or both ends such as oil storage tanks and natural draught cooling towers in which the ratio of the diameter or minimum lateral dimension to the wall thickness is of the order of 100 or more are prone to ovalling oscillations. These oscillations are characterized by periodic radial deformation of the hollow structure.

7 Buildings and structures that may be subjected to significant wind excited oscillations. It is to be noted that wind induced oscillations may occur at wind speeds lower than the design wind speed.

8 Analytical methods for the evaluation of response of dynamic structures to wind loading can be found in the special publications.

9 In assessing wind loads due to such dynamic phenomenon as galloping, flutter and ovalling, in the absence of the required information either in the special publications or other literature, expert advice should be sought including experiments on models in boundary layer wind tunnels.

9.2 Motion due to Vortex Shedding

9.2.1 *Slender Structures*

For a structure, the vortex shedding frequency f_s shall be determined by the following formula:

$$f_s = \frac{S_t \overline{V}_{z,H}}{b}$$

where

S_t = Strouhal number,

$\overline{V}_{z,H}$ = hourly mean wind speed at height z, and

b = breadth of a structure or structural member normal to the wind direction in the horizontal plane

a) *Circular structures* — For structures of circular in cross-section:

S_t = 0.20 for D $\overline{V}_{z,H}$ less than 6 m²/s, and

= 0.25 for D $\overline{V}_{z,H}$ more than or equal to 6 m²/s.

b) *Rectangular structures* — For structures of rectangular cross-section:

$S_t = 0.10$

NOTES

1 Significant cross wind motions may be produced by vortex shedding if the natural frequency of the structure or structural element is equal to the frequency of the vortex shedding within the range of expected wind speeds. In such cases, further analysis should be carried out on the basis of special publications.

2 Unlined welded steel chimney stacks and similar structures are prone to excitations by vortex shedding.

3 Intensification of the effects of periodic vortex shedding has been reported in cases where two or more similar structures are located in close proximity, for example at less than 20b apart, where b is the dimension of the structure normal to the wind.

4 The formulae given in 8.2.1 (a) is valid for infinitely long cylindrical structures. The value of S_t decreases slowly as the ratio of length to maximum transverse width decreases, the reduction being up to about half the value, if the structure is only three times higher than its width. Vortex shedding need not be considered if the ratio of length to maximum transverse dimension is less than 2.0.

10 DYNAMIC WIND RESPONSE

10.1 General

Tall buildings which are 'wind sensitive' shall be designed for dynamic wind loads. Hourly mean wind speed is used as a reference wind speed to be used in dynamic wind analysis. For calculation of along wind loads and response (bending moments, shear forces, or tip deflections) the Gust Factor (GF) method is used as specified in **10.2**. The across wind design peak base overturning moment and tip deflection shall be calculated using **10.3**.

10.2 Along Wind Response

For calculation of along-wind load effects at a level s on a building/structure, the design hourly mean wind pressure at height z shall be multiplied by the Gust Factor (GF). This factor is dependent on both the overall height h and the level s under consideration (*see* Fig. 9). For calculation of base bending moment and deflection at the top of the building/structure s should be taken as zero.

The design peak along wind base bending moment, (M_a) shall be obtained by summing the moments resulting from design peak along wind loads acting at different heights, z, along the height of the building/structure and can be obtained from,

$$M_a = \Sigma F_z Z$$

$$F_z = C_{f,z} A_z \bar{p}_d G$$

where

F_z = design peak along wind load on the building/structure at any height z

A_z = the effective frontal area of the building/structure at any height z, in m²

$\bar{p}_d$ = design hourly mean wind pressure corresponding to $\bar{V}_{z,d}$ and obtained as $0.6\ \bar{V}_{z,d}^2$ (N/m²)

$\bar{V}_{z,d}$ = design hourly mean wind speed at height z, in m/s (see **6.4**)

$C_{f,z}$ = the drag force coefficient of the building/structure corresponding to the area A_z

G = Gust Factor and is given by.

$$= 1 + r\sqrt{\left[g_v^2 B_s (1+g)^2 + \frac{H_s g_R^2 SE}{\beta} \right]}$$

where

r = roughness factor which is twice the longitudinal turbulence intensity, $I_{h,i}$ (see **6.5**),

g_v = peak factor for upwind velocity fluctuation,
= 3.0 for category 1 and 2 terrains, and
= 4.0 for category 3 and 4 terrains,

B_s = background factor indicating the measure of slowly varying component of fluctuating wind load caused by the lower frequency wind speed variations

$$= \frac{1}{\left[1 + \frac{\sqrt{0.26(h-s)^2 + 0.46 b_{sh}^2}}{L_h} \right]}$$

where

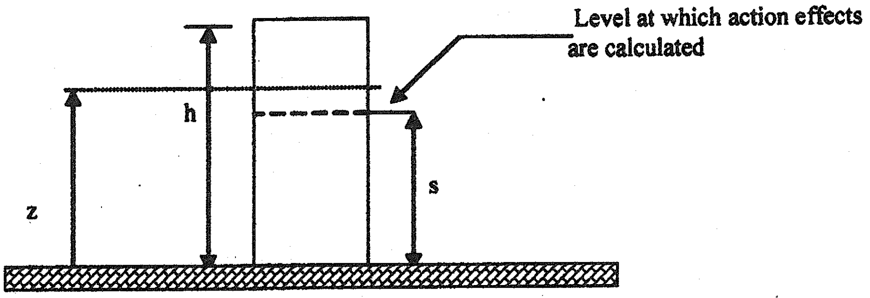
b_{sh} = average breadth of the building/structure between heights s and h

L_h = measure of effective turbulence length scale at the height, h, in m

$= 85\left(\frac{h}{10}\right)^{0.25}$ for terrain category 1 to 3

$= 70\left(\frac{h}{10}\right)^{0.25}$ for terrain category 4

ϕ = factor to account for the second order turbulence intensity



NOTE — 0 < s < h, and s < z < h

FIG. 9 NOTATIONS FOR HEIGHTS

$$= \frac{g_v I_{h,i} \sqrt{B_s}}{2}$$

$I_{h,i}$ = turbulence intensity at height h in terrain category i

H_s = height factor for resonance response

$$= 1+\left(\frac{s}{h}\right)^2$$

S = size reduction factor given by:

$$= \frac{1}{\left[1+\frac{3.5 f_a h}{\overline{V}_{h,d}}\right]\left[1+\frac{4 f_a b_{0h}}{\overline{V}_{h,d}}\right]}$$

where

b_{0h} = average breadth of the building/structure between 0 and h.

E = spectrum of turbulence in the approaching wind stream

$$= \frac{\pi N}{\left(1+70.8 N^2\right)^{5/6}}$$

where

N = effective reduced frequency

$$= \frac{f_a L_h}{\overline{V}_{h,d}}$$

f_a = first mode natural frequency of the building/structure in along wind direction, in Hz

$\overline{V}_{h,d}$ = design hourly mean wind speed at height, h in m/s (*see* **6.4**)

β = damping coefficient of the building/structure (*see* Table 36)

g_R = peak factor for resonant response

$$= \sqrt{\left[2 \ln(3\,600 f_a)\right]}$$

Table 36 Suggested Values of Structural Damping Coefficients

(*Clause* 10.2)

Sl No. (1)	Kind of Structure (2)	Damping Coefficient, β (3)
i)	Welded steel structures	0.010
ii)	Bolted steel structures/RCC structures	0.020
iii)	Prestressed concrete structures	0.016

10.2.1 *Peak Acceleration in Along Wind Direction*

The peak acceleration at the top of the building/structure in along wind direction ($\ddot{\hat{x}}$ in m/s²) is given by the following equation:

$$\ddot{\hat{x}} = \left(2\pi f_a\right)^2 \bar{x}\, g_R r \sqrt{\frac{SE}{\beta}}$$

where

$\bar{x}$ = mean deflection at the position where the acceleration is required. Other notations are same as given in **10.2**.

For computing the peak acceleration in the along wind direction, a mean wind speed at the height of the building/structure, $\overline{V}_h$ corresponding to a 5 year mean return period shall be used. A reduced value of 0.011 is also suggested for the structural damping, β for reinforced concrete structures.

10.3 Across Wind Response

This section gives method for determining equivalent static wind load and base overturning moment in the across wind direction for tall enclosed buildings and towers of rectangular cross-section. Calculation of across wind response is not required for lattice towers.

The across wind design peak base bending moment M_c for enclosed buildings and towers shall be determined as follows:

$$M_c = 0.5 g_h \bar{p}_h b h^2 \left(1.06 - 0.06\, k\right) \sqrt{\left(\frac{\pi C_{fs}}{\beta}\right)}$$

where

g_h = a peak factor,

$= \sqrt{\left[2 \ln(3600 f_c)\right]}$ in cross wind direction;

$\bar{p}_h$ = hourly mean wind pressure at height h, in Pa;

b = the breadth of the structure normal to the wind, in m;

h = the height of the structure, in m;

k = a mode shape power exponent for representation of the fundamental mode shape as represented by:

$$\psi(z) = \left(\frac{z}{h}\right)^k$$

f_c = first mode natural frequency of the building/structure in across wind direction, in Hz.

The across wind load distribution on the building/structure can be obtained from M_c using linear

distribution of loads as given below:

$$F_{z,c} = \left(\frac{3M_c}{h^2}\right)\left(\frac{z}{h}\right)$$

where $F_{z,c}$ = across wind load per unit height at height z.

10.3.1 *Peak Acceleration in Across Wind Direction*

The peak acceleration at the top of the building/structure in across-wind direction ($\hat{\ddot{y}}$ in m/s²) with approximately constant mass per unit height shall be determined as follows:

$$\hat{\ddot{y}} = 1.5\frac{g_h \bar{p}_h b}{m_0}(0.76+0.24k)\sqrt{\left(\frac{\pi C_{fs}}{\beta}\right)}$$

Typical values of the mode shape power exponent, k are as follows:

a) uniform cantilever, $k = 1.5$

b) slender framed structure (moment resisting), $k = 0.5$

c) building with a central core and moment resisting façade, $k = 1.0$

d) lattice tower decreasing in stiffness with height, or a tower with a large mass at the top, $k = 2.3$

C_{fs} = across wind force spectrum coefficient generalized for a linear mode. (*see* Fig. 10 and Fig. 11).

β = damping coefficient of the building/structure (*see* Table 36).

m_0 = the average mass per unit height of the structure in, kg/m.

10.4 Combination of Along Wind and Across Wind Load Effects

The along wind and across wind loads have to be applied simultaneously on the building/structure during design.

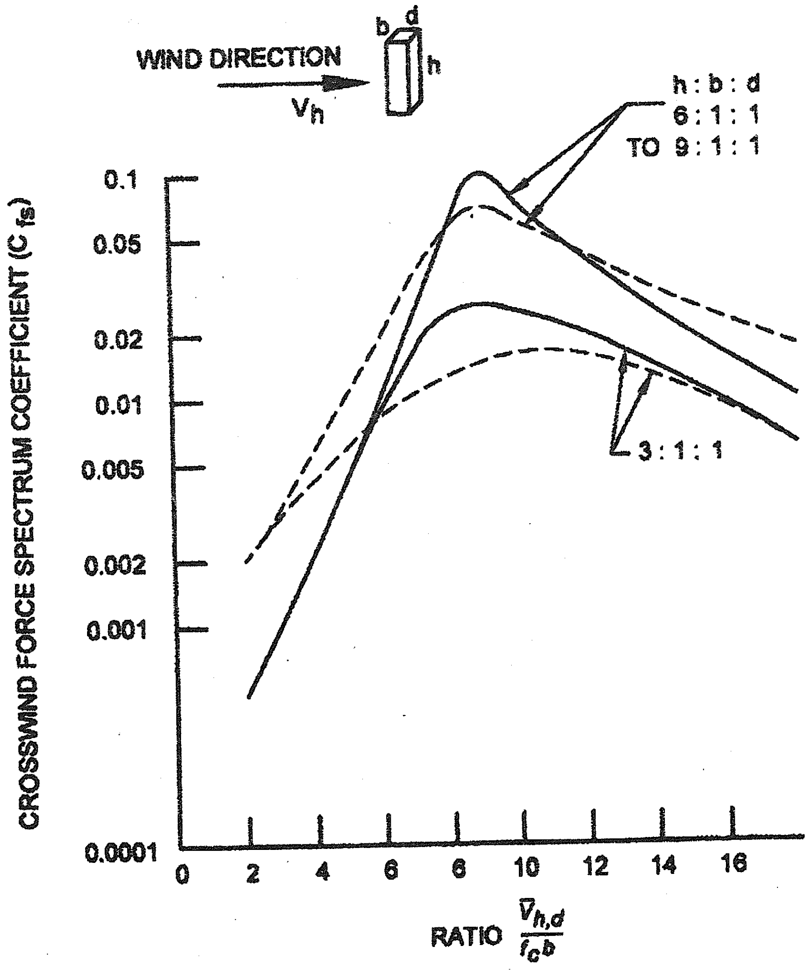
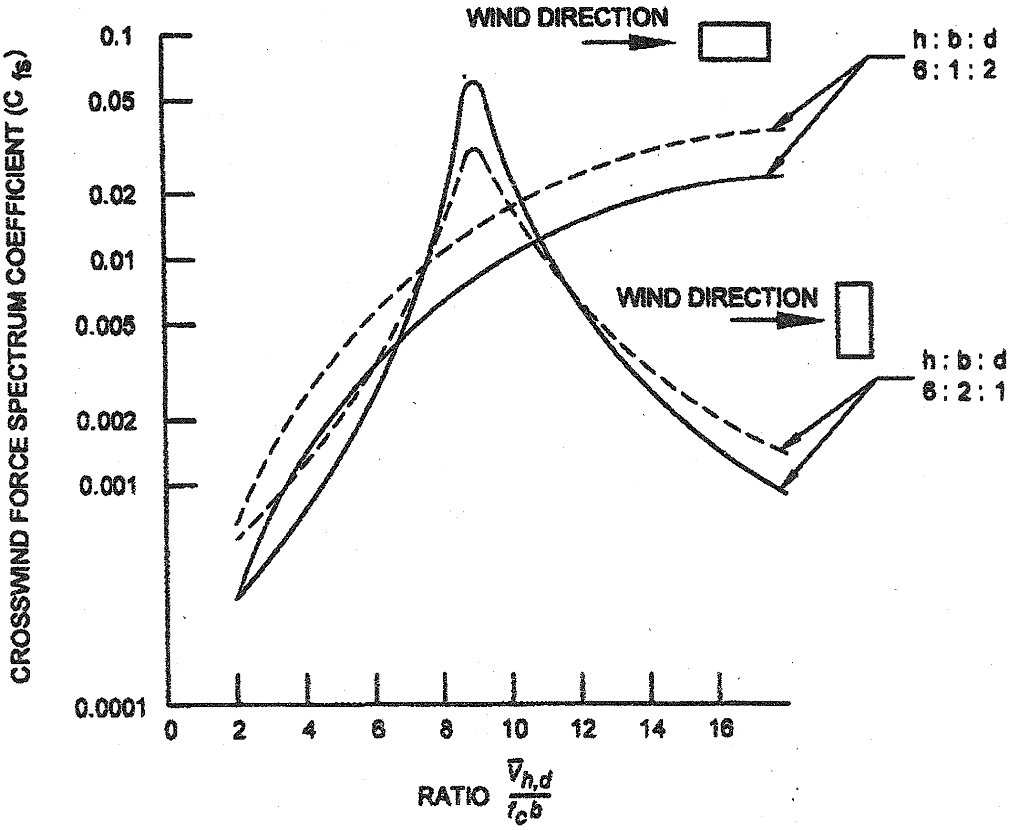


FIG. 10 VALUES OF THE CROSS WIND FORCE SPECTRUM COEFFICIENT FOR SQUARE SECTION BUILDINGS



Legend:

— Turbulence Intensity of 0.12 at 2/3 h

- - Turbulence Intensity of 0.20 at 2/3 h

FIG. 11 VALUES OF THE CROSS WIND FORCE SPECTRUM COEFFICIENT FOR 2:1 AND 1 : 2 RECTANGULAR SECTION BUILDINGS

ANNEX A

(*Clause* 6.2)

BASIC WIND SPEED AT 10 m HEIGHT FOR SOME IMPORTANT CITIES / TOWNS

City/Town	Basic wind Speed m/s
Agra	47
Ahmedabad	39
Ajmer	47
Almora	47
Amritsar	47
Asansol	47
Aurangabad	39
Bahraich	47
Bengaluru	33
Barauni	47
Bareilly	47
Bhatinda	47
Bhilai	39
Bhopal	39
Bhubaneshwar	50
Bhuj	50
Bikaner	47
Bokaro	47
Chandigarh	47
Chennai	50
Coimbatore	39
Cuttack	50
Darbhanga	55
Darjeeling	47
Dehradun	47
Delhi	47
Durgapur	47
Gangtok	47
Guwahati	50
Gaya	39
Gorakhpur	47
Hyderabad	44
Imphal	47
Jabalpur	47
Jaipur	47
Jamshedpur	47
Jhansi	47
Jodhpur	47

City/Town	Basic wind Speed m/s
Kanpur	47
Kohima	44
Kolkata	50
Kozhikode	39
Kurnool	39
Lakshadweep	39
Lucknow	47
Ludhiana	47
Madurai	39
Mandi	39
Mangalore	39
Moradabad	47
Mumbai	44
Mysore	33
Nagpur	44
Nainital	47
Nasik	39
Nellore	50
Panjim	39
Patiala	47
Patna	47
Puducherry	50
Port Blair	44
Pune	39
Raipur	39
Rajkot	39
Ranchi	39
Roorkee	39
Rourkela	39
Shimla	39
Srinagar	39
Surat	44
Tiruchirappalli	47
Trivandrum	39
Udaipur	47
Vadodara	44
Varanasi	47
Vijayawada	50
Vishakapatnam	50

ANNEX B

[*Clause* 6.3.2.4 (b)(ii)]

CHANGES IN TERRAIN CATEGORIES

B-1 LOW TO HIGH TERRAIN CATEGORY NUMBER

In cases of transition from a low terrain category number (corresponding to a low terrain roughness) to a higher terrain category number (corresponding to a rougher terrain), the velocity profile over the rougher terrain shall be determined as follows:

a) Below height h_x, the velocities shall be determined in relation to the rougher terrain; and

b) Above height h_x, the velocities shall be determined in relation to the less rough (more distant) terrain.

B-2 HIGH TO LOW TERRAIN CATEGORY NUMBER

In cases of transition from a more rough to a less rough terrain, the velocity profile shall be determined as follows:

a) Above height h_x, the velocities shall be determined in accordance with the rougher (more distant) terrain; and

b) Below height h_x, the velocity shall be taken as the lesser of the following:

   1) that determined in accordance with the less rough terrain, and

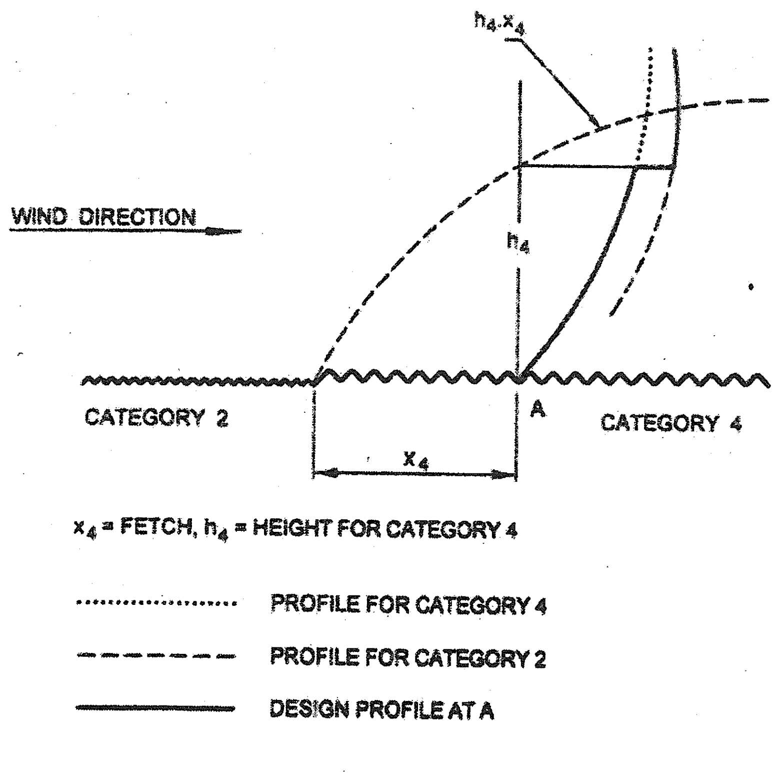
   2) the velocity at height h_x as determined in relation to the rougher terrain

   NOTE — Examples of determination of velocity profiles in the vicinity of a change in terrain category are shown in Figs.12a and 12b.

B-3 MORE THAN ONE CATEGORY

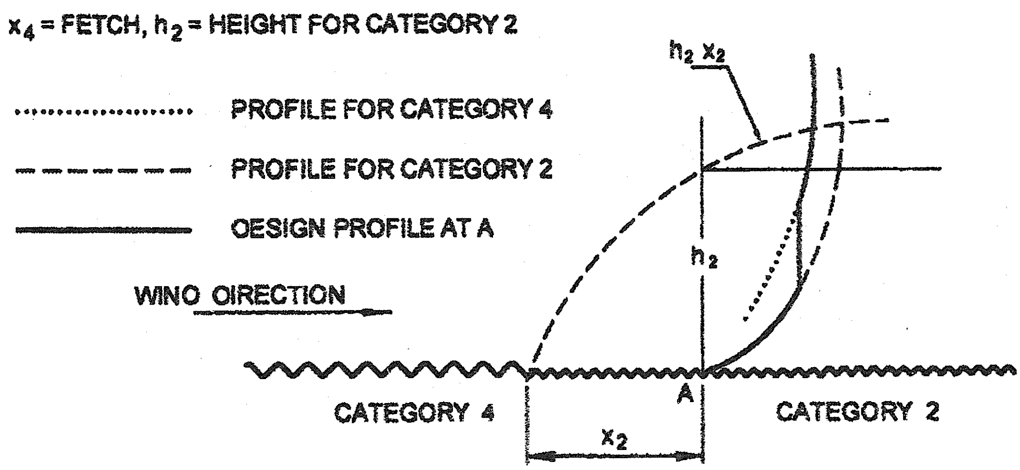
Terrain changes involving more than one category shall be treated in similar way to that described in B-1 and B-2.

NOTE — Examples involving three terrain categories are shown in Fig. 12c.

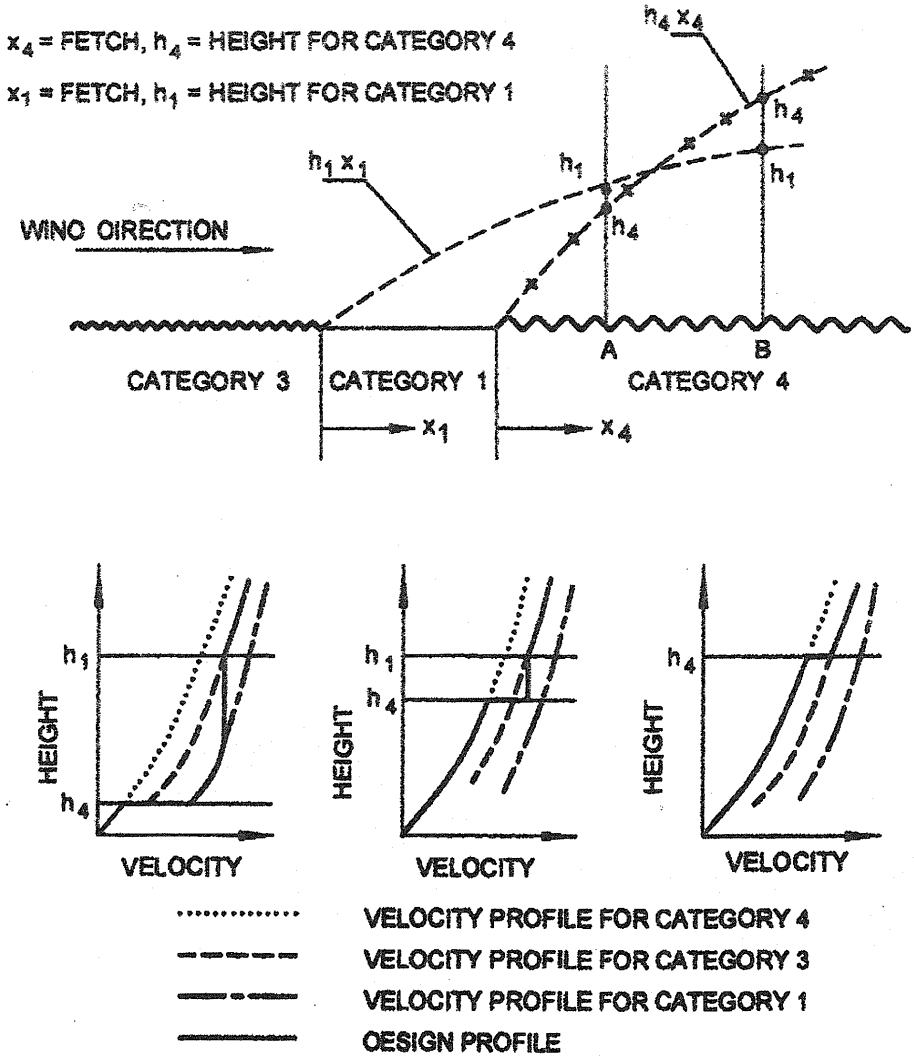


a) DETERMINATION OF VELOCITY PROFILE NEAR A CHANGE IN TERRAIN CATEGORY
(Less rough to more rough)

FIG. 12 VELOCITY PROFILES IN THE VICINITY OF A CHANGE IN TERRAIN CATEGORY



b) Determination of Velocity Profile Near a Change in Terrain Category (More rough to less rough)



c) Determination of Design Profile Involving more than One Change in Terrain Category

FIG. 12 VELOCITY PROFILES IN THE VICINITY OF A CHANGE IN TERRAIN CATEGORY

ANNEX C

(*Clause* 6.3.3.1)

EFFECT OF A CLIFF OR ESCARPMENT ON EQUIVALENT HEIGHT ABOVE GROUND (k_3 FACTOR)

C-1 The influence of the topographic feature is considered to extend 1.5 L_e upwind and 2.5 L_e downwind of the summit of crest of the feature where L_e is the effective horizontal length of the hill depending on slope as indicated below (see Fig. 13).

Slope	L_e
$3° < \theta_s \leq 17°$	L
$\theta_s > 17°$	$Z / 0.3$

where

L = actual length of the upwind slope in the wind direction,

Z = effective height of the topography feature, and

θ_s = upwind slope in the wind direction.

In case, the zone in downwind side of the crest of the feature is relatively flat ($\theta_s < 3°$) for a distance exceeding L_e, then the feature should be treated as an escarpment. Otherwise the feature should be treated as a hill or ridge. Examples of typical features are given in Fig. 13.

NOTES

1 No difference is made, in evaluating k_3 between a three dimensional hill and two dimensional ridge.

2 In undulating terrain, it is often not possible to decide whether the local topography to the site is significant in terms of wind flow. In such cases, the average value of the terrain upwind of the site for a distance of 5 km should be taken as the base level from wind to assess the height, Z, and the upwind slope θ, of the feature.

C-2 TOPOGRAPHY FACTOR, k_3

The topography factor k_3 is given by the following:

$$k_3 = 1 + C s_0$$

where C has the following values:

Slope	*C*
$3° < \theta_s \leq 17°$	1.2 (Z/L)
$\theta s > 17°$	0.36

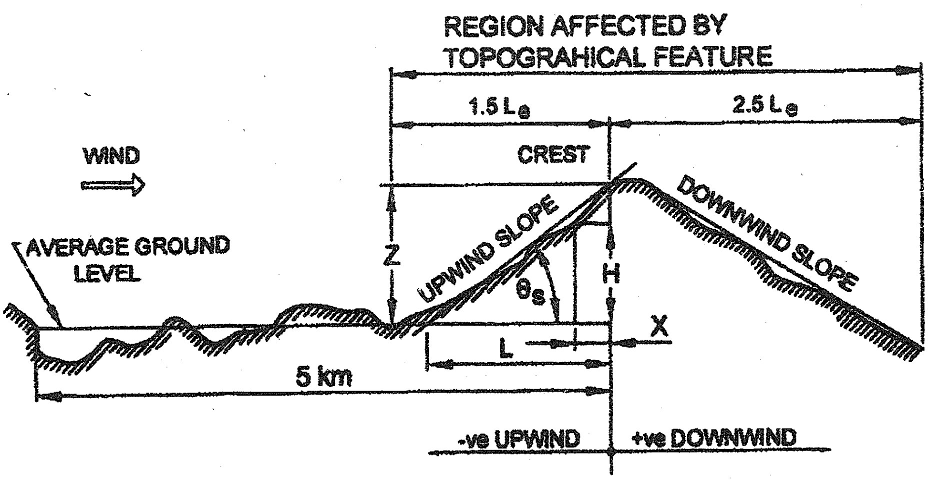
and s_0 is a factor derived in accordance with C-2.1 appropriate to the height, H above mean ground level and the distance, x, from the summit or crest relative to the effective length, Le

C-2.1 The factor, s_0 should be determined from:

a) Fig. 14 for cliffs and escarpments, and

b) Fig. 15 for ridges and hills.

NOTE – Where the downwind slope of a hill or ridge is more than 3°, there will be large regions of reduced accelerations or even shelter and it is not possible to give general design rules to cater for these circumstances. Values of s_0 from Fig. 15 may be used as upper bound values.



13 (a) GENERAL NOTATIONS

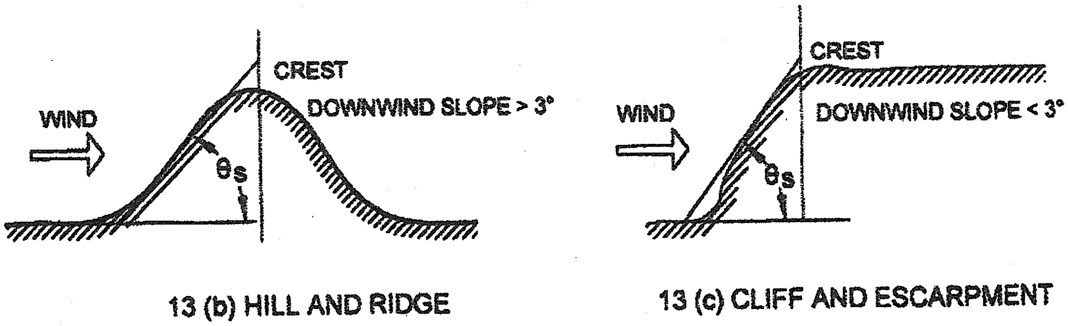


FIG. 13 TOPOGRAPHICAL DIMENSIONS

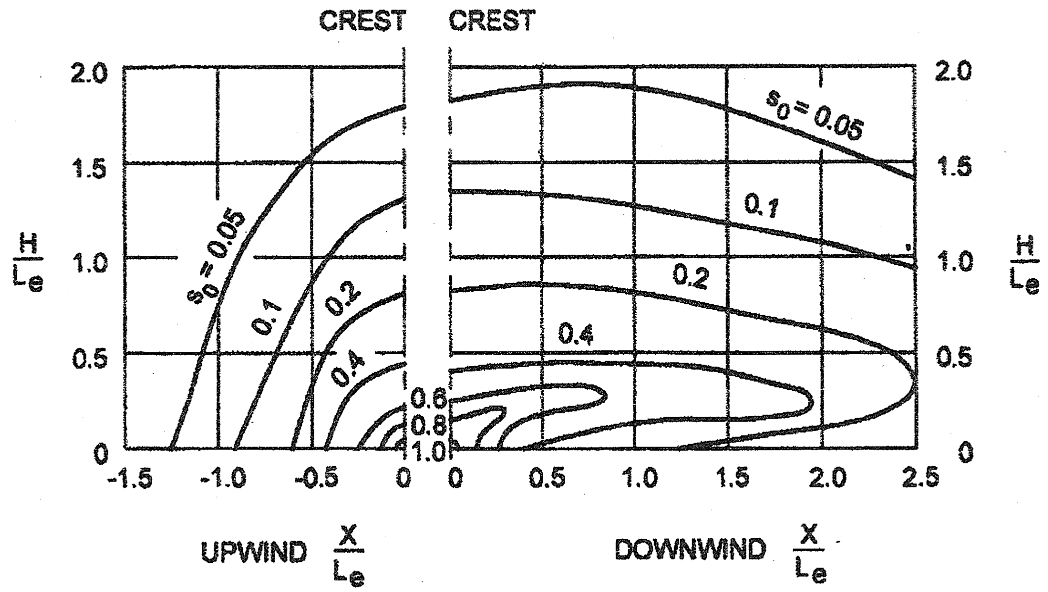


FIG. 14 FACTOR s FOR RIDGE AND HILL

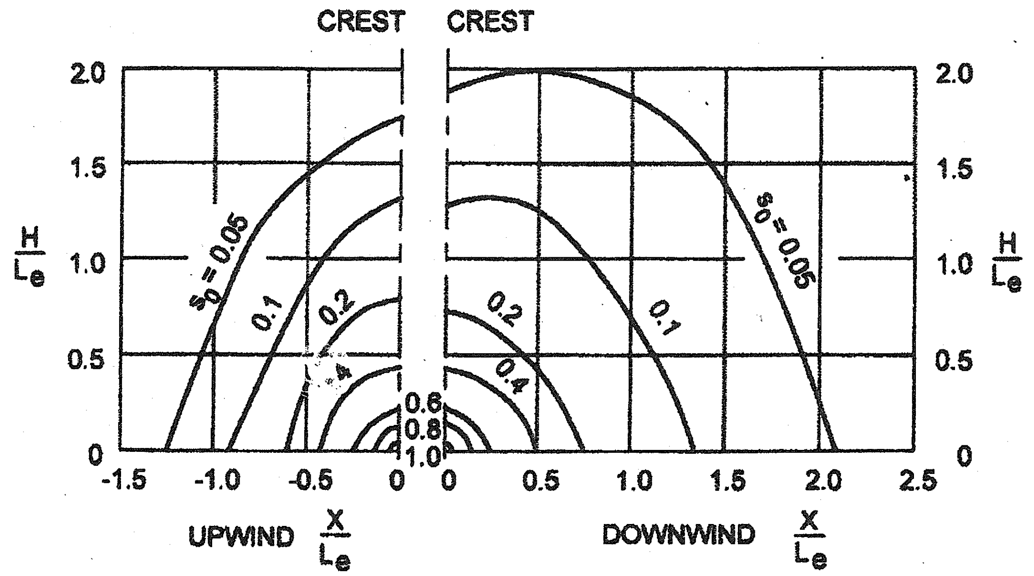


FIG. 15 FACTOR s FOR CLIFF AND ESCARPMENT

ANNEX D

(*Clauses* 7.4.2.2, 7.4.3.2 *and* 7.4.3.3)

WIND FORCE ON CIRCULAR SECTIONS

D-1 The wind force on any object is given by:

$F = C_f A_e p_d$

where

C_f = force coefficient,

A_e = effective area of the object normal to the wind direction, and

p_d = design pressure of the wind.

For most shapes, the force coefficient remains approximately constant over the whole range of wind speeds likely to be encountered. However, for objects of circular cross-section, it varies considerably.

For a circular section, the force coefficient depends on the way in which the wind flows around it and is dependent upon the velocity and kinematic viscosity of the wind and diameter of the section. The force coefficient is usually quoted against a non-dimensional parameter, called the Reynolds number, which takes into account of the velocity and viscosity of the flowing medium (in this case the wind), and the member diameter.

Reynolds number, $Re = D\bar{V}_d / \nu$

where

D = diameter of the member

$\bar{V}_d$ = design hourly mean wind speed

ν = kinematic viscosity of the air which is 1.46×10^{-5} m²/s at 15°C and standard atmospheric pressure.

Since in most natural environments likely to be found in India, the kinematic viscosity of the air is fairly constant, it is convenient to use $D\bar{V}_d$ as the parameter instead of Reynolds number and this has been done in this code.

The dependence of a circular section's force coefficient on Reynolds number is due to the change in the wake developed behind the body.

At a low Reynolds number, the wake is as shown in Fig. 16 and the force coefficient is typically 1.2. As Reynolds number is increased, the wake gradually changes to that shown in Fig. 17; that is, the wake width d_w decreases and the separation point denoted as sp, moves from front to the back of the body.

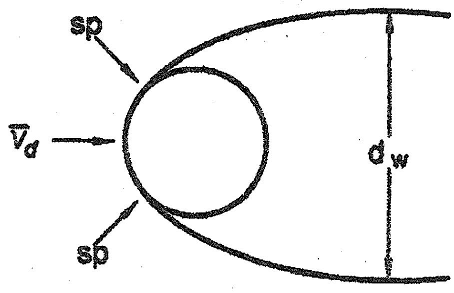


FIG. 16 WAKE IN SUB CRITICAL FLOW

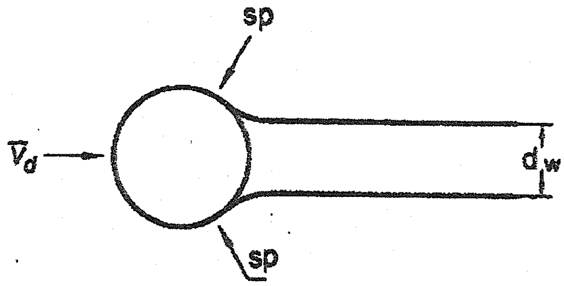


FIG. 17 WAKE IN SUPER CRITICAL FLOW

As a result, the force coefficient shows a rapid drop at a critical value of Reynolds number followed by a gradual rise as Reynolds number is increased still further.

The variation of C_f with parameter $D\bar{V}_d$ is shown in Fig. 5 for infinitely long circular cylinders having various values of relative surface roughness (ε/D) when subjected to wind having an intensity and scale of turbulence typical of built-up urban areas. The curve for a smooth cylinder (ε/D) = 1×10^{-5} in a steady air stream, as found in a low-turbulence wind tunnel, is also shown for comparison.

It can be seen that the main effect of free-stream turbulence is to decrease the critical value of the parameter $D\bar{V}_d$. For subcritical flows, turbulence can produce a considerable reduction in C_f below the steady air-stream values. For supercritical flows, this effect becomes significantly smaller.

If the surface of the cylinder is deliberately roughened such as by incorporating flutes, riveted construction, etc, then the data given in Fig. 5 for appropriate value of $\varepsilon/D > 0$ shall be used.

NOTE — In case of uncertainty regarding the value of ε to be used for small roughness, ε/D shall be taken as 0.001.

ANNEX E

(Foreword)

COMMITTEE COMPOSITION

(Excluding Water Resources Development Division) Sectional Committee, CED 37

Organization	*Representative(s)*
In personal capacity (*80, SRP Colony, Peravallur, Chennai 600 082*)	DR N. LAKSHMANAN (***Chairman***)
Atomic Energy Regulatory Board, Mumbai	SHRI L. R. BISHNOI SHRI A. D. ROSHAN (*Alternate*)
Bharat Heavy Electricals Limited, New Delhi	SHRI S. S. MANI
Central Building Research Institute (CSIR), Roorkee	DR A. K. PANDEY DR RAJESH DEOLIYA (*Alternate*)
Central Electricity Authority, New Delhi	SHRI R. B. WALIMBE SHRI S. K. ROY CHOWDHURY (*Alternate*)
Central Public Works Department, New Delhi	SHRI A. K. GARG SHRI RAJESH KHARE (*Alternate*)
Central Water Commission, New Delhi	DIRECTOR C&MDD (E&NE) DIRECTOR C&MDD (N&W) (*Alternate*)
Engineer-in-Chief's Branch (MES), NewDelhi	BRIG SANDEEP RAWAT SHRI V. K. JATAV (*Alternate*)
Engineers India Limited, New Delhi	SHRI VINAY KUMAR SHRI SUDHIR CHATURVEDI (*Alternate*)
Gammon India Limited, Mumbai	SHRI S. W. DESHPANDE SHRI AVINASH Y. MAHENDRAKAR (*Alternate*)
Indian Institute of Technology Madras, Chennai	DR DEVDAS MENON DR A MEHER PRASAD (*Alternate*)
Indian Institute of Technology Kanpur, Kanpur	DR VINAY K. GUPTA
Indian Institute of Technology Roorkee, Roorkee	DR PREM KISHAN DR S.K.KAUSHIK (*Alternate*)
Indian Metrological Department, New Delhi	SHRI K. RATNAM
M.N. Dastur & Company Limited, Kolkata	SHRI A. DAS GUPTA SHRI SATYAKI SEN (*Alternate*)
MECON Limited, Ranchi	SHRI ONKAR SAHAY SHRI A. K. BEG (*Alternate*)
Ministry of Shipping, Road Transport & Highways, New Delhi	SHRI S. K. PURI SHRI SATISH KUMAR, SE (P-9) (*Alternate*)
Muncipal Corporation of Greater Mumbai, Mumbai	Deputy Municipal Commissioner (ENGG) City Engineer (*Alternate*)
National Buildings Construction Corporation Limited, New Delhi	SHRI RAKESH MARYA SHRI L. P. SINGH (*Alternate*)
National Council for Cement and Building Materials, Ballabgarh	SHRI V. V. ARORA SHRI S. SHARMA (*Alternate*)
National Thermal Power Corporation, Noida	SHRI H. KUNDU SHRI MASOOM ALI (*Alternate*)
Research, Designs & Standards Organization, Lucknow	Joint Director Standards (B&S) JT Director Stnds (B&S) SB-I (*Alternate*)
RITES Limited, Gurgaon	SHRI ASHOK KUMAR MATHUR
Structural Engineering Research Centre (CSIR), Chennai	DR S. SELVI RAJAN DR P. HARIKRISHNA (*Alternate*)
TCE Consulting Engineers Limited, Mumbai	SHRI A. P. MULL SHRI A. DUTTA (*Alternate*)
The Institution of Engineers (India) Ltd, New Delhi	SHRI K. B. RAJORIA

In personal capacity, (*P-121, Sanjay Nagar, Ghaziabad 201 001*)	Shri S. K. Agarwal
In personal capacity, (*142 Deshbandhu Apartments, New Delhi 110 019*)	Shri G. P. Lahiri
In personal capacity, (*61, Civil Lines, Roorkee 247 667*)	Dr Prem Krishna
BIS Directorate General	Shri D. K. Agrawal, Scientist 'F' and Head (Civil Engg) [Representing Director General (*Ex-officio*)]

Member Secretaries
Shri S. Chaturvedi
Scientist 'F' (Civil Engg), BIS
and
Shri S. Arun Kumar
Scientist 'C' (Civil Engg), BIS

AMENDMENT NO. 1 APRIL 2016
TO
IS 875 (PART 3) : 2015 DESIGN LOADS (OTHER THAN EARTHQUAKE) FOR BUILDINGS AND STRUCTURES — CODE OF PRACTICE

PART 3 WIND LOADS

(Third Revision)

(*Second cover page, Foreword, para* 6, *line* 1) — Substitute 'discipline' *for* 'descriptive'.

(*Second cover page, Foreword, para* 6, (c)) — Substitute 'k_2' *for* 'k_2'.

(*Third cover page, Foreword, para after* (j), *line* 8) — Insert 'anemometer' after 'with the help of'.

(*Page* 2, *clause* **3.1**) — Substitute 'C_f' *for* 'C_{fd}'.

(*Page* 3, *Symbol r*) — Insert ', $I_{h,i}$' after 'height h'.

(*Page* 3) — Substitute '$\bar{V}_{z,d}$' *for* '$\bar{V}_{d,z}$'.

(*Page* 6, *Fig.* 1) — Insert the following notes at the end of the figure.

'NOTES

1 The occurrence of a tornado is possible in virtually any part of India. They are particularly more severe in the northern parts of India. The recorded number of these tornados is too small to assign any frequency. The devastation caused by a tornado is due to exceptionally high winds about its periphery, and the sudden reduction in atmospheric pressure at its centre, resulting in an explosive outward pressure on the elements of the structure. The regional basic wind speeds do not include any specific allowance for tornados. It is not the usual practice to allow for the effect of tornados unless special requirements are called for as in the case of important structures such as, nuclear power reactors and satellite communication towers.

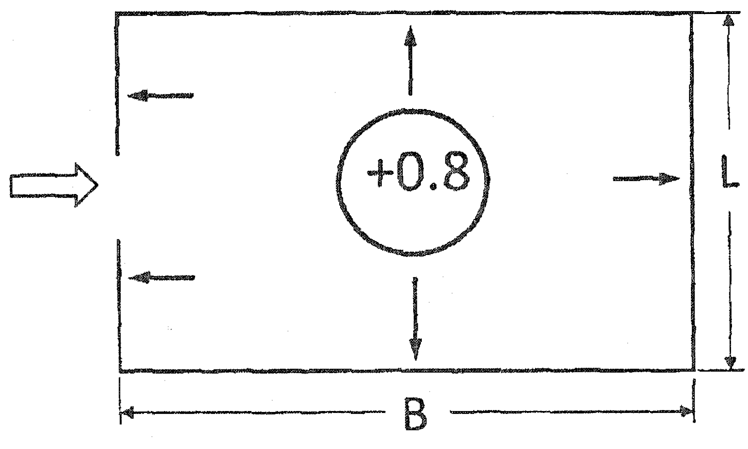
2The total number of cyclonic storms that have struck different sections of east and west coasts are included in Fig. 1, based on available records for the period from 1877 to 1982. The figures above the line (between the stations) indicate the total number of severe cyclonic storms with or without a core of hurricane winds (speeds above 87 km/h) and the figures in the brackets below the lines indicate the total number of cyclonic storms. These have been included only as additional information.'

(*Page* 10, *Table* 4, *) — Substitute the following for the existing: '*Linear interpolation for intermediate values of A is permitted.'.

(*Page* 11, *clause* **7.3.3.3**, *para* 2) — Substitute 'The solidity ratio Φ ' *for* 'The solidity ratio f'.

(*Page* 11, *clause* **7.3.3.3**, *para* 2, *lines* 3, 5 *and* 10) — Substitute ' Φ ' *for* 'f'.

[*Page* 12, *Fig.* 2(b), *Right-topmost figure*] — Substitute the existing figure with the figure below:

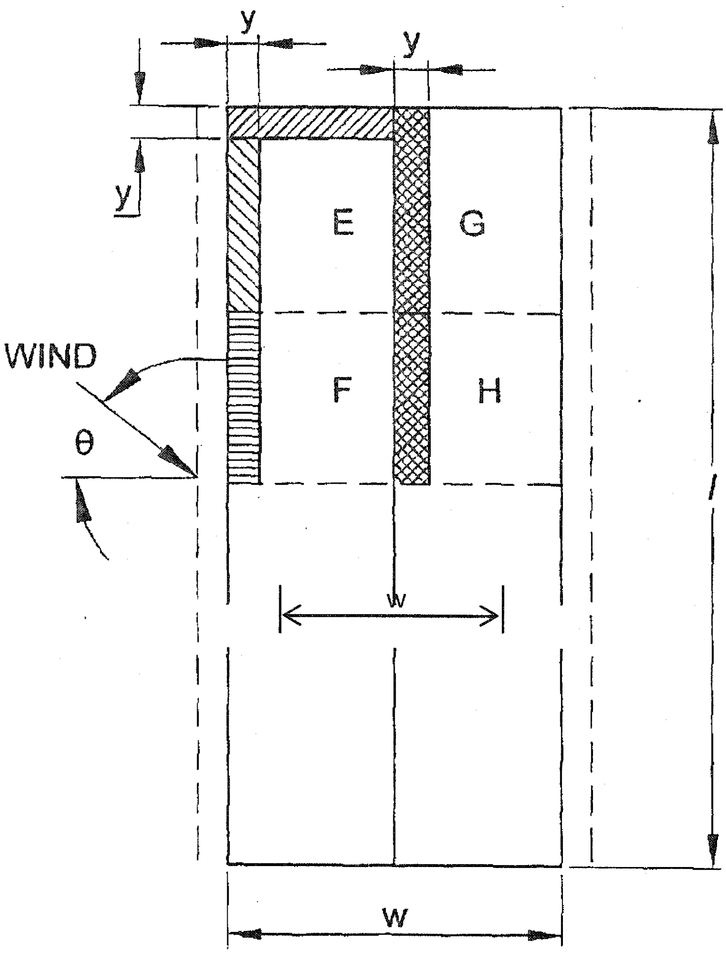


Price Group 4

(*Page*13, *Table* 5, first row under BUILDING HEIGHT RATIO $\frac{1}{2}<\frac{h}{w}\leq\frac{3}{2}$) — Substitute '$1<\frac{l}{w}\leq\frac{3}{2}$' *for* '$1\leq\frac{l}{w}\leq\frac{3}{2}$'.

(*Page* 13, *Table* 5, second row under BUILDING HEIGHT RATIO $\frac{1}{2}<\frac{h}{w}\leq\frac{3}{2}$) — Substitute '$\frac{3}{2}<\frac{l}{w}<4$' *for* '$\frac{3}{2}\leq\frac{l}{w}<4$'.

(*Page* 14, *Table* 6, *bottommost figure*) — Substitute the following figure for the existing:



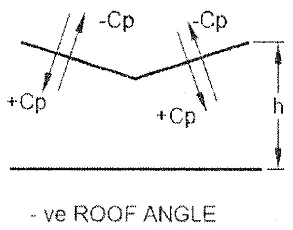
KEY PLAN

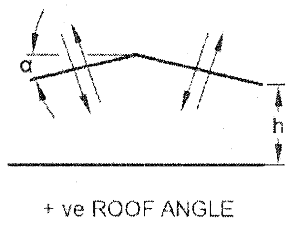
$y = h$ or $0.15\,w$ whichever is the lesser.

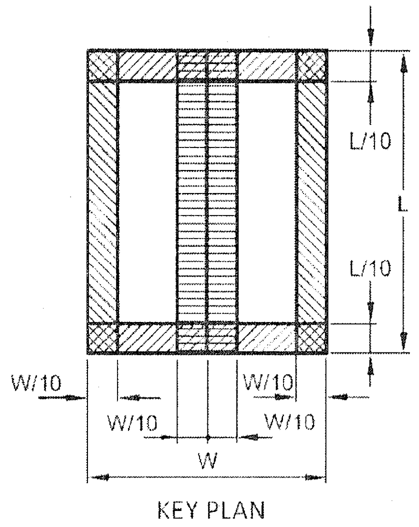
(*Page* 17, *Table* 8) — Insert ', α' after 'ROOF ANGLE'.

(*Page* 17, *Table* 8, *Note* 2) — Substitute 'overhangs.' *for* 'overhangs,'.

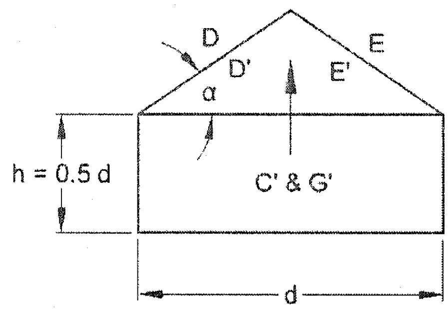
(*Page* 18, *Table* 9) — Substitute the following figures for the existing:

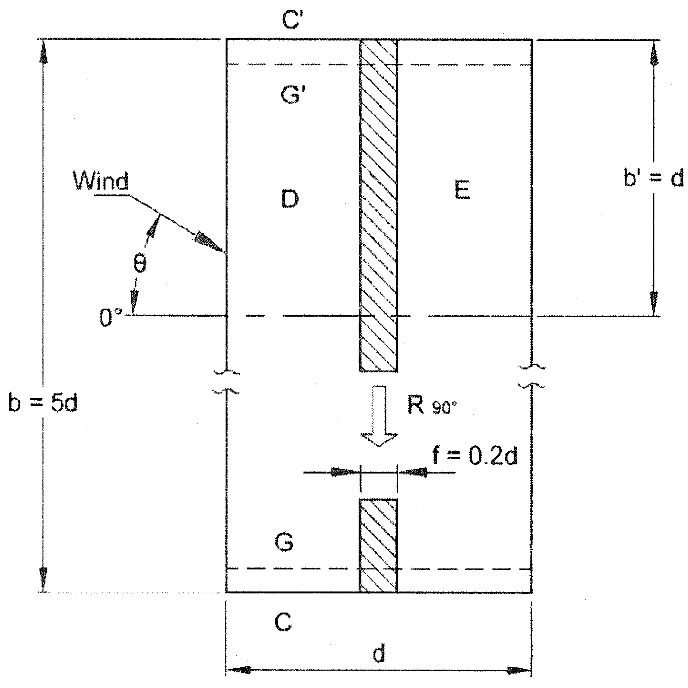






(*Page* 19, *Table* 10) — Substitute the following figures for the existing:





(*Page* 19, *Table* 10) — Substitute the following for the existing table below figure:

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	+0.6	-1.0	-0.5	-0.9				
45°	+0.1	-0.3	-0.6	-0.3				
90°	-0.3	-0.4	-0.3	-0.4	-0.3	+0.8	+0.3	-0.4
FOR ALL VALUE OF θ	FOR J : C_pTop = 1.0, $C_p$bottom = -0.2 Tangentially acting friction : $R_{90°} = 0.05\ p_d bd$							

(*Page* 20, *Table* 11) — Substitute the following for the existing table below figure:

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	+0.1	+0.8	-0.7	+0.9				
45°	-0.1	+0.5	-0.8	+0.5				
90°	-0.4	-0.5	-0.4	-0.5	-0.3	+0.6	+0.3	-0.4
180°	-0.3	-0.6	+0.4	-0.6				
FOR ALL VALUE OF θ	FOR J : C_pTop = -1.5, $C_p$bottom = 0.5 Tangentially acting friction : $R_{90°} = 0.05\ p_d bd$							

(*Page* 21, *Table* 12, *below figure, line* 3) — Substitute 'θ = 90°' *for* 'θ = θ0°'.

(*Page* 21, *Table* 12) — Substitute the following for the existing table below figure:

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	-1.0	+0.3	-0.5	+0.2				
45°	-0.3	+0.1	-0.3	+0.1				
90°	-0.3	0	-0.3	0	-0.4	+0.8	+0.3	-0.6
FOR ALL VALUE OF θ	FOR *f* : C_pTop = -1.0, $C_p$bottom = 0.4 Tangentially acting friction : $R_{90°} = 0.1\ p_d bd$							

(*Page* 22, *Table* 13, *top figure*) — Substitute 'h'=0.8h' *for* 'h'=0.θh'.

(*Page* 22, *Table* 13) — Substitute the following for the existing table below figure:

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	-1.3	+0.8	-0.6	0.7				
45°	-0.5	+0.4	-0.3	+0.3				
90°	-0.3	0	-0.3	0	-0.4	+0.8	+0.3	-0.6
180°	-0.4	-0.3	-0.6	-0.3				
FOR ALL VALUE OF θ	FOR f: C_pTop = -1.6, $C_p$bottom = -0.9 Tangentially acting friction : $R_{90°} = 0.1\ p_d bd$							

(*Page* 23, *Table* 14, top figure) — Delete'x'.

(*Page* 24, *Table* 15) — Delete'x'.

(*Page* 24, *Table* 15, bottom) — Substitute 'Tangentially' *for* 'Tengentially'.

(*Page* 26, *Table* 17, bottom) — Substitute the following for the existing entry:

270	Similar to 90°, h_1, h_2, h_3 are needed to be reckoned from the windward edge in the same order

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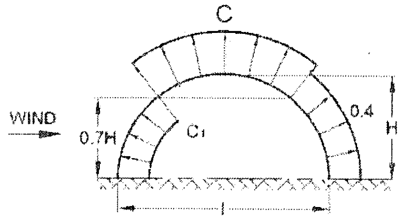
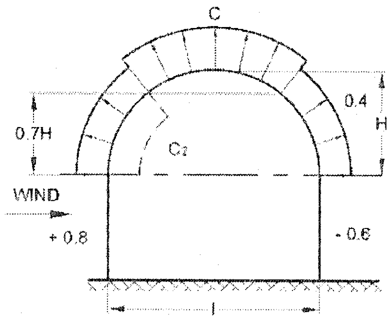
(*Page* 27, *Table* 18) — Substitute the following for the existing table:

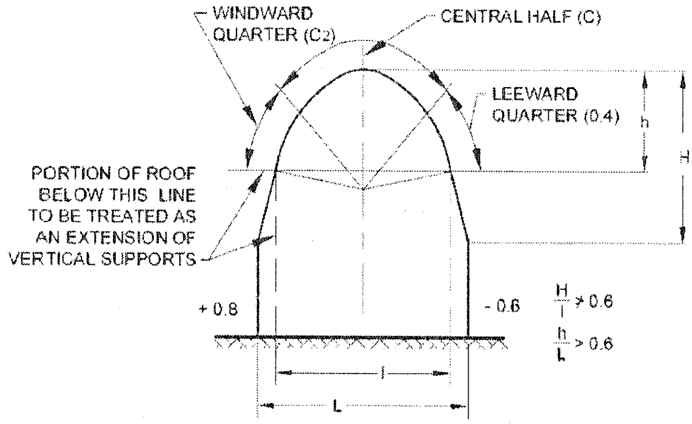
Table 18 External Pressure Coefficients (C_{pe}) for Curved Roofs
(*Clause* 7.3.3.6)



a) ROOF SPRINGING FROM GROUND LEVEL



b) ROOF ON ELEVATED STRUCTURE



c) DOUBLE CURVED ROOFS

VALUES OF C, C_1 and C_2

H/l	C	C_1	C_2	C_2
0.1	- 0.8	+ 0.1	- 0.8	+ 0.05
0.2	- 0.9	+ 0.3	- 0.7	+ 0.1
0.3	- 1.0	+ 0.4	- 0.3	+ 0.15
0.4	- 1.1	+ 0.6	+ 0.4	-
0.5	- 1.2	+ 0.7	+ 0.7	-

NOTE: When the wind is blowing normal to gable ends, C_{pe} may be taken as equal to -0.7 for the full width of the roof over a length of $l/2$ from the gable ends and -0.5 for the remaining portion.

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(*Page*28, *Table* 19, *figures*) – Substitute 'D' *for* '*d*' in both figures.

(*Page* 31, *Table* 21, *figures*, y-axis, between 0.4 and 0.8) – Substitute '0.6' *for* '0.8'.

(*Page* 31, *Table* 21) –Substitute the following for the existing entry:

e	*See* **7.3.3.5**

(*Page* 32, *Table* 22) – Substitute the following for the existing entry:

C_{pe}	-0.6	+0.7	*See* Table 21 for combined roofs

[*Page* 34, *clause* **7.4.1** (a)] — Substitute the following for the existing:
'a) If $h \leq b, F' = C_f'(d-4h)bp_d + C_f'(d-4h)2hp_d$, and'

(*Page* 36, *Table* 25, *Title*) — Substitute '(Clause 7.4.2.1)' *for* '(Clause7.4.2.2)'.

(*Page* 39, *Fig.*5) — Substitute 'C_f = FORCE COEFFICIENT' *for* 'C_f = DRAG COEFFICIENT'.

(*Page* 39, *Table* 26) — Substitute 'FORCE COEFFICIENT, C_f' *for* 'DRAG COEFFICIENT C_f'.

[*Page* 40, *Table* 28, *Sl* No. (ii), *col* 2] — Substitute '$D\overline{V}_d \geq 6m^2/s$' for the existing information given in bracket.

[*Page* 40, *Table* 28, *Sl No.* (iii), *col* 2] — Substitute '$b\overline{V}_d \geq 6m^2/s$' for the existing information given in bracket.

(*Page* 41, *Table* 29, *Title*) — Substitute '[Clause 7.4.3.2(a)]' *for* '[Clause 7.4.3.2 (b)]'.

(*Page* 42, *clause* **7.4.3.4**, *line* 10) — Substitute 'spacing' *for* 'spac-ing'.

(*Page* 42, *Table* 30, *Title*) — Substitute the '(l/D = 100)' in the title in place '(L/D = 100)'.

[*Page* 42, *Table* 30, *Sl No.* (i) *and* (ii), *col* 2] — Substitute the following for the existing values:

(1)	(2)	(3)	(4)	(5)	(6)
i)	$D\overline{V}_d < 6\ m^2/s$	1.2	1.2	1.2	1.3
ii)	$D\overline{V}_d \geq 6\ m^2/s$	0.5	0.7	0.9	1.1

(*Page* 42, *Table* 31, Force Coefficient C_t for) — Substitute 'Force Coefficient, C_f for' *for* 'Force Coefficient C_t for'.

(*Page* 42, *Table* 31, *col* 1) — Substitute '0.2' *for* '02'.

(*Page* 42, *Table* 31, *col* 4, *sub-sub heading*) — Substitute 'Super Critical Flow ($D\overline{V}_d \geq 6\ m^2/s$)' for the existing.

(*Page* 43, *Table* 32, *Title*) — Substitute '**η**' *for* '***H***'.

(*Page* 44, *Table* 34, *sub-heading*) — Substitute 'Subcritical Flow ($D\overline{V}_d < 6\ m^2/s$)' for the existing and 'Supercritical Flow ($D\overline{V}_d \geq 6\ m^2/s$)' for the existing.

(*Page* 44, *clause* **8.2**, *line* 4) — Substitute '*x*' *for* '(*x*)'.

(*Page* 44, *Table* 35) — Substitute 'Subcritical Flow ($D\overline{V}_d$ <6 m^2/s) All Wind Directions' for the existing and 'Supercritical Flow ($D\overline{V}_d \geq$ 6 m^2/s) All Wind Directions' for the existing.

(*Page* 45, *Fig.*7) — Substitute 'x' *for* 'X'.

(*Page* 45, *Fig.* 8, *caption*) — Substitute '(CLAUSE **8.3**)' *for* '(CLAUSE 7.3)'.

(*Page* 46, *clause* **9.2.1**, *Note* 2, *line* 1) — Substitute the following for the existing:

'2 Unlined welded steel cylindrical structures…'

(*Page* 46, *clause* **9.2.1**, *Note* 4, *line* 1) — Substitute '**9.2.1** (a)' *for* '**8.2.1** (a)'.

(*Page* 47, *clause* 10.2, *line* 14) — Substitute '$M_a = \sum F_z z$' *for* '$M_a = \sum F_z Z$'.

(*Page* 47, *clause* **10.2**, *line* 28) — Substitute '$(1+\phi)^2$' *for* '$(1+g)^2$' in formula of Gust factor.

(*Page* 48, *clause* **10.3**, *line* 13) — Substitute '$\overline{p}_h$' *for* 'p_h'.

(*Page* 49, *Fig.* 10, x-axis) — Substitute '…6 8 10…' *for* '…6 6 10…'.

[*Page* 53, *Fig.*12(b)] — Substitute 'DESIGN PROFILE AT A' *for* 'OESIGN PROFILE AT A'.

[*Page* 53, *Fig.*12(b)] — Substitute 'WIND DIRECTION' *for* 'WINO OIRECTION'.

[*Page* 53, *Fig.*12(c)] — Substitute 'WIND DIRECTION' *for* 'WINO OIRECTION'.

(*Page* 54, *clause* **C-2**, *line* 6) — Substitute 'θ_s' *for* 'θs'.

(*Page* 54, *clause* **C-2**, *line* 9) — Substitute 'distance, X' *for* 'distance, x'.

[*Page* 54, *Fig.*13(a)] — Substitute 'REGION AFFECTED BY TOPOGRAPHICAL FEATURE' *for* 'REGION AFFECTED BY TOPOGRAHICAL FEATURE'.

(*Page* 55, *Fig.*14, *caption*) — Substitute the following for the existing caption:

FIG. 14 FACTOR s_0 FOR CLIFF AND ESCARPMENT'

(*Page* 55, *Fig* 15, *caption*) — Substitute the following for the existing caption:

'FIG. 15 FACTOR s_0 FOR RIDGE AND HILL'

(*Page* 56, *Fig.*17) — Substitute 's_p' *for* 'sp'.

(*Page* 56, *clause* **D-1,** *para* 7, *line* 5) — Substitute 's_p' *for* 'sp'.

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